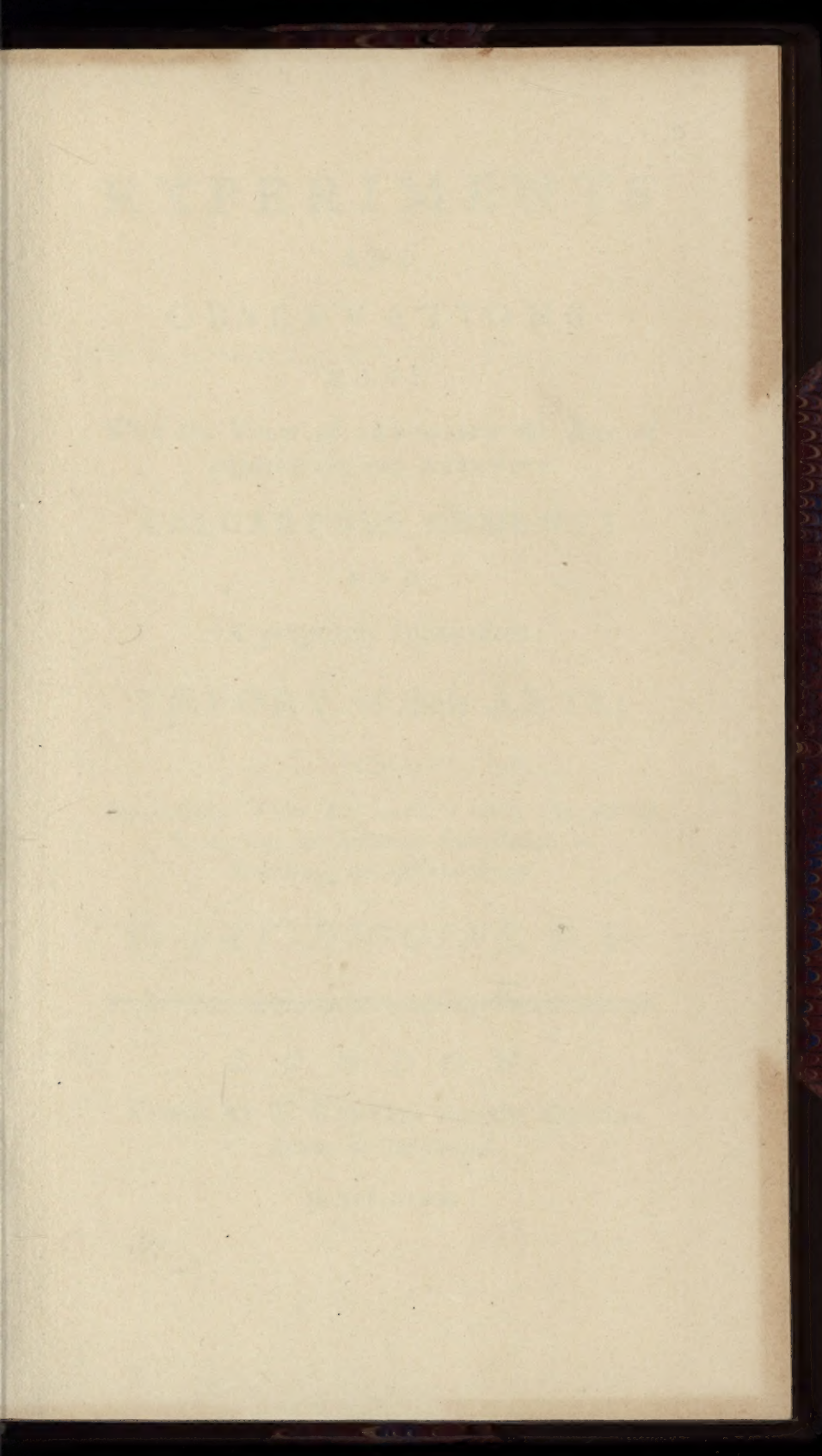
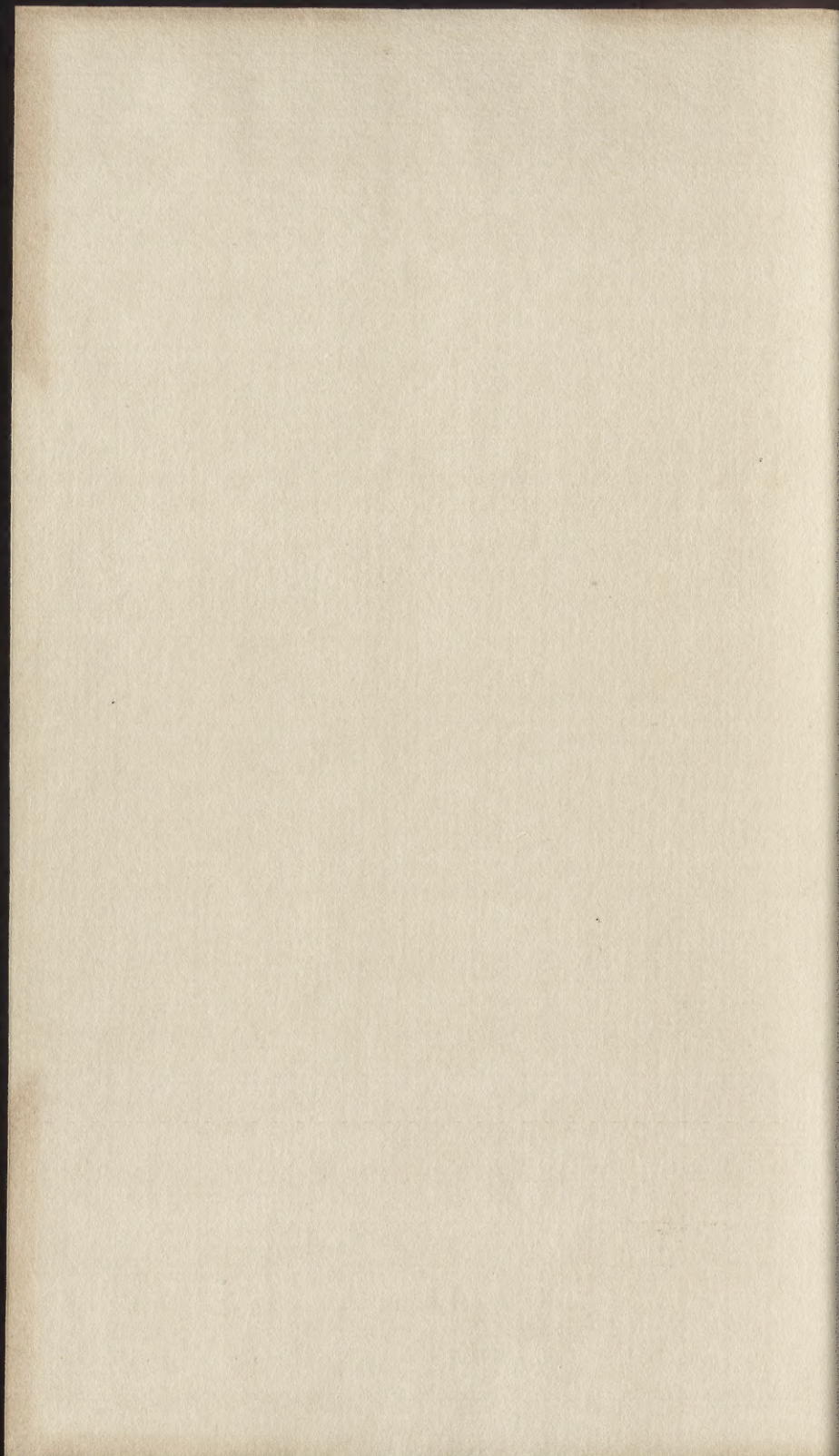


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EXPERIMENTS

AND

OBSERVATIONS

MADE

With the VIEW of IMPROVING the ART of
COMPOSING and APPLYING

CALCAREOUS CEMENTS

AND

Of preparing Quick-lime:

THEORY of these ARTS;

AND

Specification of the AUTHOR'S cheap and durable
CEMENT, for Building, Incrustation or
Stuccoing, and artificial Stone.

By *BRY. HIGGINS*, M. D.

L O N D O N:

Printed for T. CADELL, opposite *Catherine-
Street*, in the *Strand*.

M, DCC, LXXX.

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MDCCLXXX.

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SECTION



SECTION I.

AMONGST the instances and experiments produced in my public Courses of Chemistry in 1774, to illustrate my notions of the polarity of matter, divers mixtures of lime sand and water, were particularly considered: and these being preserved and methodically arranged, according to the plan of this school, soon suggested to me an enquiry which I have prosecuted with great attention ever since that time.

As the strength and duration of our most useful and expensive buildings depend chiefly on the goodness of the cement with which they are constructed, I looked to the improvement of mortar as a subject of great importance, in this country particularly, where the weather is so variable and trying, and the mortar commonly used is so bad,

B

that

that the timbers of houses last longer than the walls, unless the mouldering cement be frequently replaced by pointing. But seeing that many years are requisite for the greatest degree of induration which cementitious mixtures like mortar can acquire, or for our discovering the imperfections of them; and that the life of man is too short to allow any considerable improvements of them to be derived from such experiments as had hitherto been made, I resolved in the beginning of the year 1775 to investigate more closely than I had hitherto done, the principles on which the induration and strength of calcarious cements depend; not doubting that this would lead me by an untried path to recover or to excel the Roman cement, which in aqueducts and the most exposed structures has withstood every trial of fifteen hundred or two thousand years.

SECTION II.

*Experiments and Observations on Lime-stone
and Lime.*

I Had already learned from the chaste and philosophic productions of Dr. Black; that calcareous stones which burn to lime, contain a considerable quantity of the elastic fluid called fixable air or acidulous gas, which in combination with the earthy matter forms a great part of the mass and weight of these stones; and that the difference between lime-stone or chalk and lime, consists chiefly in the retention or expulsion of this matter.

EXPECTING to learn something further relative to lime, and particularly, to discover the cause of the differences which appear in cements made with different kinds of lime, I made the following experiments.

I PROCURED specimens of different kinds of lime-stone and chalk, and breaking them

into small fragments, I burned them in crucibles lined with lime to prevent the pieces from touching their crucibles and vitrifying at those surfaces which lay next to them : I likewise burned the like specimens in crucibles perforated to admit a free current of air through them ; and lastly, I exposed three pounds of either specimen to a graduated fire in an earthen retort which was barely sufficient to hold this quantity, and whose neck I lengthened by fitting to it a glass conical tube luted at the juncture with four parts of lime one of fine sand and as much dissolved glue such as the carpenters use, as was sufficient to form a paste ; having found this luting to hold fast and to be impervious to any elastic fluid or liquor expelled in such processes. I immersed the extremity of the glass tube in mercury, and inverting a bottle filled with mercury over the extremity of the tube, I received whatever water or elastic fluid was expelled from the calcarious stones by the fire, and I measured the quantity of these by instantly applying a fresh bottle as soon as the former was filled. When all the water was expelled, or when I knew the quantity of it contained in the
lime-

lime-stone or chalk, I used a basin of water and bottles filled with water, making allowance for the matter imbibed by the water.

To avoid a tedious detail of particulars which do not immediately relate to the chief object of this essay, I shall only mention summarily the most pertinent observations which these and other experiments afforded; endeavouring that the terms in which I shall deliver these observations shall describe the experiments sufficiently for those who are acquainted with modern chemistry.

OBSERVATION I.

LIME-STONE or chalk heated only to redness, in a covered crucible, or in a perforated crucible through which the air circulates freely, looses only about one-fourth of it's weight, however long this heat be continued. The sort of lime so formed effervesces considerably in acids, flakes slowly and partially to a powder which is not white, but is grey or brown, and heats but little in flaking.

IN describing heats I do not regard the heat in particular parts of the fuel, but

only that which the bodies themselves are made to conceive equally through their whole mass, whether they be in vessels which defend them considerably from the action of the fire, or fully exposed to it by their immediate contact with the fuel,

OBSERVATION. 2.

LIME-STONE or chalk exposed to a heat barely sufficient to melt copper, whether in a perforated crucible or otherwise, loses about one third of its weight in twelve hours, and very little more in any longer time. This lime effervesces but slightly in acids; it heats much sooner and more strongly than the foregoing, when water is sprinkled on it, and it flakes more equably and to a whiter powder. In a variety of trials, this lime appeared to be in the same state with the best pieces of lime, prepared in the common lime-kilns. For the quantities of acidulous gas obtainable from both by a stronger heat, or in solution, were nearly equal; they flaked in equal times, with the same phenomena, and to the same colour and condition of the powder.

OBSERVATION. 3.

THE lime burned in perforated crucibles, or in the naked fire, is whiter than that burned in common crucibles covered, in which case the air has not so free access to it; altho' the loss of weight be the same in both; but this latter kind of lime, in flaking, affords as white a powder as any other which has lost equally of its weight. Whatever portion of phlogiston it retains to produce this dusky colour, is either detached in the flaking, or does not sensibly affect the lime in any use, to which I applied it.

OBSERVATION. 4.

WHEN dry chalk or lime-stone is used, in the process above described for making lime in close vessels, and for examining the matter which is expelled by fire, the quantity of water obtainable from it by any heat, is so inconsiderable as to deserve no notice in our mensuration of that matter.

OBSERVATION. 5.

CHALK or lime-stone heated gradually in these close vessels, loses very little acidulous gas until it begins to redden: after this the

elastic fluid issues from it the quicker as the heat is made greater, and continues to issue until the retort glows with a vivid white heat sufficient to melt steel.

OBSERVATION. 6

FORTY-EIGHT ounces of chalk yield twenty-one ounces of elastic fluid, the first portions of which are turbid as they issue, but soon become clear without loss of bulk, by the condensation of the watery vapour: the remaining portions issue transparent and invisible. One thirty-sixth of this elastic fluid, and sometimes much more of it, is phlogistic air, the remainder is pure acidulous gas.

OBSERVATION. 7

THE residuary lime of forty-eight ounces of chalk, urged with such heat to the total expulsion of the elastic fluids, weighs only twenty-seven ounces, whilst it is red hot. When it cools it weighs more by reason of the air which it imbibes as the fire escapes from it.

OBSERVATION 8.

WHEN no more heat is employed than is necessary for the expulsion of these elastic fluids, the residuary matter is found contracted sensibly in volume, and is good lime, tho' not so white as lime prepared in the usual way. With water it flakes instantly, grows hissing hot and perfectly white. The flaked powder is exceedingly fine, except in those parts of the lime which lay in contact with the retort, which are always superficially vitrified, because clay and lime promote the vitrification of each other.

OBSERVATION 9.

THE lumps of this lime, immersed in lime-water, or boiling water, to expel the air which such spongy bodies imbibe in cooling, dissolve in marine acid without shewing any sign of effervescence,

OBSERVATION 10.

LIME-STONE or chalk gradually heated in a crucible, or on the bed of a reverberatory furnace, or in contact with the fuel in a wind furnace, does not become perfectly noneffervescent and similar to the lime last described

scribed, in flaking instantly, and growing hissing hot when water is sprinkled on it, until it has, after a strong red heat of six or eight hours, sustained a white heat for an hour or more. I understand by a white heat, that which is sufficient to melt cast iron completely.

OBSERVATION. II.

LIME-STONES heated sufficiently to reduce them to lime which flakes instantly with the signs above described, and which is perfectly noneffervescent, do not in general lose so much of their weight as chalk-stone does, under the like treatment. Some lime-stones lose little more than a third of their weight. Those which lose the most, flake the quickest and to the finest powder; and those which lose the least, flake the slowest and to a gritty powder composed of true lime and particles chiefly gypseous.

OBSERVATION. 12.

THE quantity of gypsum, or of other earthy matter in well burned lime, is discoverable by weak marine acid; for this dissolves
and

and washes away the lime, leaving the gypsum to be measured when dry, the part of the gypsum which dissolves being too small to deserve any attention; and if any other earthy matter or any saline matter existed in the lime-stone, it vitrifies with part of the calcarious matter in the heat necessary for making noneffervescent lime, and is separable by the means last mentioned, and even by a fine sieve in most instances,

OBSERVATION. 13.

WHEN lime-stone or chalk is suddenly heated to the highest degree above described, or a little more, it vitrifies in the parts which touch the fire vessels, or furnace, or fuel, and the whole of it becomes incapable of flaking freely or acting like lime. Lime-stone is the more apt to vitrify in such circumstances, as it contains more gypseous or argillaceous particles; and oyster-shells or cockle-shells vitrify more easily than lime-stone or chalk, when they are suddenly heated; which I impute to their saline matter; for when they are long weathered, they do not vitrify so easily.

OBSERVATION. 14.

THE agency of air is no further necessary in the preparation of lime, than as it operates in the combustion of the fuel.

OBSERVATION. 15.

CALCARIOUS stones acquire the properties of lime in the most eminent degree, when they are slowly heated in small fragments until they appear to glow with a white heat, when this is continued until they become noneffervescent, but is not augmented. The art of preparing good lime consists chiefly in these particulars.

OBSERVATION 16.

THAT lime is to be accounted the purest and fittest for experiment, whether it be the best for mortar or not, which flakes the quickest and heats the most in flaking, which is whitest and finest when flaked, which when wetted with lime-water dissolves in marine acid or distilled vinegar without effervescence, and leaves the smallest quantity of residuary undissolved matter.

OBSER-

OBSERVATION 17.

THE quick flaking, the colour of the flaked powder, and the former acid, are the most convenient, and perhaps the best tests of the purity of lime. The whiteness denotes the lime to be free from metallic impregnation; the others shew any imperfections in the process of burning, and the heterogeneous matter inseparable from the calcareous earth by burning.

SECTION III.

Remarks on the Phlogificated Air which appeared in some of the foregoing Experiments.

AS phlogificated air had not been noticed in any experiment heretofore made on chalk or lime-stone, I resolved to examine the elastic fluid detached from them in the usual method.

I extricated several gallons of elastic fluid from chalk, during the solution of it in marine acid diluted largely with water; and after agitating this elastic fluid with the necessary quantity of water, and sometimes with lime-water, until all the acidulous gas was imbibed by them, I found a residue consisting of common air, which was about one twenty-eighth of the bulk of the acidulous gas, in some trials, in others it was much less.

As I have not had time to examine lime-stones in the same manner, or to prosecute this

this subject by other experiments, and as it does not appear sufficiently interesting in our present enquiry concerning calcareous cements, I must content myself with offering a conjecture concerning it.

THE air which is extricated during the solution of chalk, seems to be that which chalk, like other porous bodies, imbibes by capillary attraction; and it retains its proper character, because all the phlogistic matter of chalk is held in the solution. It may happen likewise that some air escapes from the water whilst it imbibes the acidulous gas, which it attracts more forcibly; and this air from the water may contribute to the bulk of that which appears in the solution of calcarious bodies. But whilst chalk is deprived of its acidulous gas by the action of fire, the air which was held in its pores, and which attracts phlogiston, is expelled in combination with phlogiston, and consequently in the form of phlogistic air; and the air contained in the pores and in the cavity of the retort, contributes to the bulk of the phlogistic air obtainable in this manner.

THIS

THIS conjecture appears the more probable when we consider, that the quantity of air imbibed by porous bodies is much greater than it appears in any experiments made with the air pump; as I shewed in my public course of chemistry in 1776, by the great increase of weight, which red hot charcoal acquired in cooling in vessels into which nothing ponderable but air was admitted. The same attractive powers which draw air into bodies, and condense it in them, resist the expansion and escape of it in the void; and detain, in such a situation of the bodies, that quantity, whose repulsive powers are counterpoised by the attractive powers.

SECTION IV.

Experiments shewing that Lime is better for Mortar as it retains less acidulous Gas, and shewing some of the Causes of the Imperfection of common Mortar.

ON divers considerations it appeared to me, that the perfection of lime for mortar consists chiefly in the total expulsion of the acidulous gas; but to be better satisfied of the truth of this opinion, I made several parcels of mortar, the description of which will be abridged by observing in this place concerning all of them, that the sand employed was coarse Thames sand, such as I use in my sand baths; that the lime was flaked as soon as it cooled after being burned, and with the smallest quantity of water necessary for this purpose; that it was sifted through a fine brass wired sieve as soon as it was fully flaked; and that each parcel of mortar was beaten and briskly formed with the quantity of water which was barely sufficient to give it the usual consistence, which

C

quantity

quantity I shall express in the pharmaceutical method by q. f.

S P E C I M E N I.

| | | | |
|--|---|---|---|
| Sand | — | — | 3 |
| Purest stone lime, described in Obs. 10, | | | |
| and 16, sect. 2, | — | | 1 |
| Water, q. f. | | | |

2.

| | | | |
|------------------------------------|---|---|---|
| Sand, | — | — | 6 |
| Purest stone lime, last mentioned, | | | 1 |
| Water, q. f. | | | |

3.

| | | | |
|---|---|---|---|
| Sand, | — | — | 3 |
| Purest chalk lime, described in obs. 10 | | | |
| and 16, sect. 2. | — | | 1 |
| Water, q. f. | | | |

4.

| | | | |
|------------------------------------|---|---|---|
| Sand, | — | — | 6 |
| Purest chalk lime, last mentioned, | | | 1 |
| Water, q. f. | | | |

5. Sand

5.
 Sand — — — 3
 Stone lime of the best kind, except that
 it was burned no further than is ex-
 pressed in the second observation of
 the second section, — 1
 Water, q. f.

6.
 Sand, — — — 6
 The last mentioned stone lime, 1
 Water, q. f.

7.
 Sand, — — — 3
 Chalk lime described in the second obser-
 vation of the second section, 1
 Water, q. f.

8.
 Sand, — — — 6
 The last mentioned chalk lime, 1
 Water, q. f.

9.
 Sand, — — — 3
 Imperfect lime, described in obs. 1, sect. 2,
 but formed of the best lime-stone, 1
 Water, q. f.

[20]

10.

| | | | |
|---------------------|---|---|---|
| Sand, | — | — | 6 |
| The foregoing lime, | | — | 1 |
| Water, q. f, | | | |

11.

| | | | |
|---|---|---|---|
| Sand, | — | — | 3 |
| Imperfect chalk lime described in obs. 1, | | | |
| fect. 2, | — | — | 1 |
| Water, q. f. | | | |

12.

| | | | |
|-------------------------|---|---|---|
| Sand, | — | — | 6 |
| The last mentioned lime | | — | 1 |
| Water, q. f. | | | |

THE lime of the 9, 10, 11, and 12 specimens was flaked whilst it was hissing hot, in a covered vessel; because it would not flake sufficiently when it was suffered to cool before the water was sprinkled on it, or when it's heat was soon dissipated by a free exposure to the air and hasty evaporation of the water: And as this lime required several hours to flake, I put it into a bottle as soon as it was cool, and kept it well stopped for twenty-four hours before I sifted it.

At

At the same time I made two specimens of mortar with common chalk lime and sand in the foregoing manner.

EACH specimen was spread as soon as it was made, to the thickness of half an inch on a plain tile previously soaked in water; the tiles were numbered and kept close by each other in an airy part of my laboratory until the mortar was dry, and then they were equally exposed, standing upright, in a place where the air sun and rain had free access to them.

In the course of fourteen or fifteen months these specimens afforded me a great deal of information, which will be noticed in due time; even in the first six months they shewed me clearly that lime is the better for mortar as it is more perfectly freed from acidulous gas. For when the comparison was made between specimens of mortar consisting of the same quantities of lime and sand, I found that the mortar made with well burned non-effervescent lime, hardened sooner and to a much greater degree, than mortar made with common lime or my stone or chalk lime

burned in the manner expressed in the second observation of the second section: and the specimens made with the stone or chalk lime which was least burned, were incomparably worse than any of the others; for they never acquired any considerable hardness, and they mouldered in the winter, the sooner as they contained more of the lime and cracked more in drying.

I observed that the specimens which contained the smaller quantities of well burned lime cracked much less than the others, or not at all; that they adhered to the tiles more firmly, and were less injured by freezing; but as the specimens made with an excess of the best burned lime were not more cracked than those made with equal quantities of the other kinds of lime, and as I could distinguish the imperfections arising from the excess of lime, from those which proceeded from the bad quality of it, I was satisfied that the lime which is most completely burned is the best for mortar,

CONSIDERING the heat, which I found necessary to extricate the last portions of acidulous gas from chalk or lime-stone, to be much
greater

greater than what is ever excited in making lime in this country or elsewhere, so far as I had observed or could learn from others ; I suspected that the lime commonly used in building is seldom or never sufficiently burned.

ON repeated trials of several specimens of such lime, I found this suspicion to be well founded, for they all effervesced and yielded acidulous gas, more or less, during the solution of them, and flaked slowly in comparison with well burned lime.

To render the effervescence conspicuous, a strong acid ought to be used, because the quantity of water in a diluted acid, retains a proportional share of the acidulous gas, and a certain quantity will retain the whole of it, and prevent the effervescence ; because the effervescence depends on the escape of the elastic fluid out of the solution. This is exemplified in the mixture of diluted vitriolic acid with the diluted solution of salt of tartar, lately recommended as a medicine by Dr. Hulme : for these solutions mix without effervescence ; although a more concentrated solution of the

alkali mixed with vitriolic acid effervesces violently.

By several experiments, the relation of which is not necessary for those who are instructed in chemistry, and would be uninteresting to others, I found that the chalk lime used in London, when taken as fresh as it can be had at the lime-wharf near Blackfriars-bridge, consists of pieces which being the best burned contain, especially in their central parts, about one-twentieth of their weight of acidulous gas; of others which contain more; and of others which retain near half their original quantity; that these last are easily discoverable by their specific gravity and hardness; and that this is the part of our common lime, which flakes the latest and of the duskiest colour, or which never flakes at all.

On a peck of this lime I sprinkled water, endeavouring to flake it equably by throwing the most water on those pieces which required it most. After the lime had stood a quarter of an hour, to flake, I sifted it through a sieve whose apertures were squares of one
sixteenth

sixteenth of an Inch; and then measuring the part which could not pass through the sieve, I found it to be about one fifth part of a peck.

I sprinkled boiling water on this coarse part, and put it in a close vessel in a warm place to accelerate the flaking of it.

I made a parcel of mortar with one part of the sifted lime and three of sand with a sufficient quantity of water; and another parcel with one part of the lime six of sand and the necessary quantity of water; and I tried them upon tiles in the manner already related, in the month of April, the weather being dry.

The foregoing coarse portion of the lime, after three hours, was flaked in several parts to a greyish powder, and I could perceive that more of it would flake in a longer time. I anticipated this by reducing the unflaked part to powder and mixing them together.

WITH

WITH this powder and sand and water in the foregoing proportions I made two specimens of mortar, and exposed them as I had done by the former.

IN a few months it appeared that the specimens last mentioned scarcely deserved the name of mortar; whilst those made with the first flaked part of the lime, were but little inferior to the best specimens made with the same proportions of chalk lime and sand.

THESE experiments confirmed me in the opinion that lime is the better for mortar as it is freer from acidulous gas; they shewed one of the causes of the badness of our common mortar; and how to manage ill-burnt lime, when better cannot be had,

THE workmen usually flake the lime mixed with the sand or gravel in great heaps, and do not skreen it until the most useful part is debased by that which flakes after five or six hours or more, and which is little better than so much powder of chalk. But if they would skreen the lime in about half an hour

hour after the water is thrown on it, the mortar would be much better, although the quantity of lime in it should be much less; for I observed in all the foregoing specimens, that those which contained the smallest quantity of lime were the best; and this quantity is much smaller than is usually employed in making mortar.

THESE remarks are applicable to mortar made with stone-lime; though the stone-lime be generally better than the chalk-lime used in London, because they are obliged to burn it better, as it will not flake otherwise.

In the brief relation of these experiments I have taken no notice of the flint kernels which frequently occur in chalk-lime, or of the other stoney masses different from the calcareous, which are found in lime-stone; because I took care that they should not lead me into any errors.

WHEN first I noticed the quantity of chalk-lime which flakes latest or not at all, I suspected that this difference might in some degree be owing to the admixture of argillaceous
or

or other matter ; but on trying these parts in acids, and after burning several specimens of them, I was convinced that the only impediment to their slacking consisted in their not being sufficiently burnt in the kiln.

SECTION V.

Experiments shewing how quickly lime imbibes acidulous gas, and is injured by Exposure to Air : Practical Inductions, &c.

IT was already known that lime exposed to air gradually loses those characters which chiefly distinguish lime from whiting or powder of chalk, and that it resumes the acidulous gas which had been expelled from it in burning. But as I was desirous to know in what measure or time these changes take place, and in what circumstances they are accelerated or retarded, I made the following Experiments.

On the 22d of August 1776 I exposed two pounds avoirdupoise of well-burned noneffervescent chalk lime, in fragments of the size of a walnut spread on a board, in a dry unfrequented room. I exposed the same quantity of this lime, at the same time and in the same manner, in a passage through which there was a constant current of air ; and I
put

put the same quantity of this lime, in fragments of the same size, in a box which might hold as much more of it, and placed the box loosely covered with its lid, close by the first portion of lime:

In 24 hours the superficial lumps of the first parcel cracked in some parts a little, those of the second cracked more, those of the third were not visibly altered. In forty-eight hours the first parcel cracked so much as to fall into smaller fragments on being moved; and these were reducible to powder by pressing them between the fingers: The second parcel underwent the like or rather a greater change, for it was more cracked and friable: The third now begun to crack in the superficial parts.

On weighing them, I found that the first parcel weighed two pounds five ounces, the second two pounds six ounces and one drachm, the third two pounds one ounce ten drachms: I then returned them to their former stations.

In six days the first parcel weighed two pounds ten ounces seven drachms; the second two pounds twelve ounces one drachm; the third two pounds four ounces eight drachms.

IN twenty-one days the first parcel weighed three pounds one drachm; the second three pounds two ounces one drachm and a half; the third two pounds six ounces eight drachms.

DURING this increase of weight the fragments split into smaller pieces, but did not fall into powder, except in a small part of them, or when they were handled.

By similar experiments made on well burned stone lime I found that this imbibes matter from the air nearly in the same manner as chalk lime, but rather more slowly; which I think is owing to its closer texture.

ON exposing common chalk or stone lime in the same way, I find that it increases in weight much less and more slowly.

To discover the quantity of water which the lime imbibed from the air, and which contributed to this increase of weight, I put each parcel in a glass retort; and adjusting to it my apparatus whereby all that is condensable is saved, whilst elastic fluids are at liberty to escape, I found that the quantity of water contained in each parcel of lime, was nearly in some, and in others accurately one-twenty-fourth of the gained weight, the remainder of the weight gained was of acidulous gas mixed with a little air, which latter I do not reckon, because it was already weighed in the lime.

If a glass bottle be filled with fragments of well-burned chalk lime, or stone lime, or shell lime, and well stopped with a ground glass stopple slightly waxed where it fits the neck of the bottle, the lime will remain unaltered in weight, or in any other known particular, for a year or two; as I have repeatedly experienced: even the phosphorescence of lime is thus preserved in its full lustre, for a year or more.

Thus it appeared that well burned lime
imbibes

imbibes acidulous gas from the air, the sooner as it is the more fully exposed to it: that lime imbibes this matter from the open air, the more greedily as it is more perfectly deprived of it previous to the exposure: that lime cannot be long preserved unaltered in any vessels which are not perfectly air-tight, but may be kept uninjured for any time in air-tight vessels filled with it: that chalk lime, by reason of its sponginess, or by some other condition of it, requires to be kept less exposed than stone lime, and well burnt lime less exposed than common lime, to render the depravation of them equal in equal times: that if acidulous gas imbibed by lime previous to its being used in mortar, be as injurious to the mortar, as the acidulous gas retained in equal quantity by ill-burned lime is, lime grows the more unfit for mortar every hour that it is kept exposed to air, whether in a heap, or in casks pervious to air.

I THINK moreover that these experiments shew that lime undergoes these changes by exposure, much quicker than has been suspected; since well burned chalk lime kept in

a dry room, imbibes near a pound of acidulous gas in three weeks, in the summer season.

Nor to trust to theory what I could prove by experiment, I did not rest satisfied with the observations and reasons which might persuade one that lime, which has imbibed some acidulous gas, is as unfit for the uses now under consideration, as lime which retains an equal quantity of the like matter by reason of the deficiency of heat in burning it.

I TRIED parcels of well burned chalk and stone lime, some of which were used fresh, others exposed two days, others six days, others twenty-one days, in the same circumstances; by making several specimens of mortar with them, and exposing the specimens in the manner already related: and in a few months I was satisfied that the specimens made with fresh lime were the hardest and best, and that the others were worse as the lime of them had been longer exposed: for those made with the lime which had been exposed three weeks and had gained four or five ounces to each pound, were so easily

easily cut or broke, so much affected by moisture and drying, and so liable to break off from the tiles, as to be utterly unfit for the ordinary uses of mortar.

AFTER this there remained no doubt that lime grows worse for mortar every day that it is kept in the usual manner in heaps or in crazy casks ; that the workmen are mistaken in thinking that it is sufficient to keep it dry ; that lime may be greatly debased without flaking sensibly ; and that the superficial parts, of any parcel of lime, which fall into small fragments or powder without being wetted, and merely by exposure to air, are quite unfit for mortar ; since this does not happen until they have imbibed a great deal of acidulous gas.

I now saw more clearly another cause of the imperfection of our common cements. The lime being exposed a considerable time before it is made into mortar, and drinking in acidulous gas all the while, the quicker as it is the better burned, is incapable of acting like good lime, when it is made into mortar ; and often approaches to the condition of whiting, which with sand and water makes

a friable perishable mass, however carefully it be dried. In London particularly they use lime which is burned, at the distance of ten or twenty miles or more, in Kent and elsewhere, with an insufficient quantity of fuel. This lime remains in the kiln, to which the air has access, for many hours after it is burned. It is exposed for some days in the transportation, and on the lime-wharfs; and it undergoes further exposure and carriage before the artist flakes it for mortar. It is no wonder that the London mortar is bad, if the imperfection of it depended solely on the badness of the lime; since the lime employed in it, is not only bad when it comes fresh from the kiln, but becomes worse before it is used, and when flaked is as widely different from good lime, as it is from powdered chalk.

SECTION VI.

Experiments and Observations made to determine whether Mortar be the better for being long kept before it is used.

I AM generally disposed to think that there is some good reason for any practice which is common to all men of the same trade, although it may not be easily reconcilable to the notions of others: and seeing that the builders flake a great quantity of lime at once, more than they can use for some days, and that all those, whom I conversed with, esteemed mortar to be the better for being long made before it is used; and that plaisterers particularly follow this opinion in making their finer mortar or stucco for plaistering within-doors; I was desirous to discover the grounds of these measures so repugnant to the notions gathered from the foregoing experiments and others.

IN the month of March 1777 I made about a peck of mortar, with one part of the

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freſheſt and beſt chalk lime flaked, fix parts of ſand, and water q. ſ; for in a great number of experiments, I obſerved that this proportion of lime was better than any larger which I had tried, or which the workmen obſerve in making mortar.

I FORMED the mortar into an hemiſpherical heap on the paved floor of a damp cellar, where it remained untouched twenty-four days. At the expiration of this time, I found it hardened at the ſurface; but moiſt, and rather friable or ſhort than plaſtic in the interior parts of it.

I BEAT the whole of it with a little water to its former conſiſtence; and with this mortar and clean new bricks, I built a wall eighteen inches ſquare and half a brick in thickneſs, in a workman-like manner. On the ſame day I made mortar of the ſame kind and quantities of freſh chalk lime and ſand, tempered in the ſame manner; and I built a wall with it, like the former, near it, and expoſed equally to the weather.

I EXAMINED the mortar in the joints of these walls every fortnight, by picking it with a pointed knife, and could perceive a very considerable difference in the hardness of them ; the mortar which was used fresh being invariably the hardest.

AT the expiration of twelve months, in pulling these walls to pieces, and by several trials of the force necessary to break the cement and separate the bricks, I found the mortar which had been used quite fresh, to be harder and to resist fracture and the separation of it from the bricks, in a much greater degree than the other specimen.

CONSIDERING that mortar exposed in the foregoing manner, must imbibe some acidulous gas, though not so much, perhaps, as the dry and spongy lumps of lime drink in, during the same time ; that the additional quantity of water necessary in beating it up the second time, must have introduced more of the like matter, as all native waters contain some quantity of it ; that the fresh exposure in the last mentioned agitation of the mortar must have contributed something to the same

effect; and lastly that the event of this experiment coincided with the notions already derived from others; I concluded that mortar grows worse every hour that it is kept before it is used in building, and that we may reckon as another cause of the badness of common mortar, that the workmen make too much at once, and falsely imagine that it is not the worse but better for being kept some time.

HAVING in consequence of these observations had a great deal of conversation with workmen on this subject, I could perceive the origin of this error.

SOME portions of every kind of lime used in this country, do not flake freely, by reason of their not being sufficiently burned, or of the admixture of gypseous or argillaceous matter; and these, like marle, flake in time, though not so quickly as the purer lime.

THE plaisterers, who use a finer kind of mortar made of sand and lime, observe that their plaister or stucco blisters, when it contains

tains small bits of unflaked lime; and as their purpose is to work their stucco to a smooth surface, and to secure it from cracking, or any such roughness as would be occasioned by the flaking or mouldering of bits of calcareous matter in the face of it; and as the hardness of the stucco is not their chief object; they very properly keep their mortar a considerable time before they use it, to the end that the bits of imperfect lime, which passed through the skreen, may have time to flake thoroughly.

It appears to me that there is another reason, which the workmen do not notice, for their process. Lime soon imbibes so much acidulous gas from the air, as to be increased in bulk, and in weight beyond the half of its former quantity; and as stucco for inside work, for the sake of a fine grain and even surface, must have a greater quantity of lime in its composition, than is necessary for cementing the grains of sand together; the incrustation would, by the access of acidulous gas after it is laid on, be apt to swell and chip and lose the even surface, if the lime were fresh when it is used in this
excessive

excessive quantity. But this inconvenience is obviated by their processes, in which the lime, whether flaked into water or otherwise, imbibes a considerable quantity of the gas, and is therefore the less apt to blister or swell, after the stucco is laid on.

THE builders considering the plaisterers mortar or stucco as a finer and better kind of mortar, think it not amiss to imitate them in those particulars which are not attended with any expence, and especially in the practice of flaking a great deal of lime at once, and of keeping the mortar made some time; and they do not seem to know, that such measures prevent the mortar from ever acquiring that degree of hardness in which the perfection of mortar truly consists.

SECTION VII.

Of the Depravation of Mortar by the common Method of using the Water; and of the Use of Lime water.

FINDING by reason and experience, the advantage of totally expelling the gas, and preventing the return of it to lime or even to mortar before it is used; and knowing that common water, which is employed in great quantities, first in flaking lime, and then in making mortar, contains a great deal of the noxious gas; it occurred to me that the vulgar process of making mortar is in this fresh instance injudicious, as it tends to injure materials otherwise good.

THEY flake lime in such a manner that almost the whole of the water is evaporated, and contributes nothing to the mortar, except so far as it deposits its gas in the lime and injures it; and then the flaked dry lime and the sand, require more water to make them
into

into mortar. I have found the quantity of water used for both these purposes, to be twice the weight of the lime, at the least.

THE quantities of acidulous gas known to be contained in the waters commonly used in making mortar, must greatly debase the lime which is thus exposed to double its weight of such water; and upon these grounds I was assured, *a priori*, that it would be a considerable improvement in mortar, to use no water in it except what has been previously freed from acidulous gas.

THIS is done in making lime-water; and the use of lime water appeared advantageous in another point of view. One seven hundredth part of lime water being lime, according to the experiments of Mr. Brandt which I find to be true; and this lime being introduced in a state of solution which favours the crystallization of it between the grains of sand, assists in cementing them together by the utmost attractive forces of its parts, if my notions of the polarity of these parts be true.

I MADE divers experiments to try the practical validity of this reasoning, and found it to be true: for on comparing specimens of mortar made with my best lime flaked with river water, and sand and water, and spread on tiles soaked in water, with other specimens made with the same proportions of lime flaked with lime water and sand and lime water, and spread on tiles previously soaked in lime water, the latter, at every age of them, were sensibly harder, and they adhered to the tiles better than the former. I must observe however, that such distinctions cannot easily be made, except by those who have a great deal of experience in these trials and comparisons. On repeated examinations of these and my other specimens, I was highly encouraged in my pursuit; for those made with lime water were better near the surface than any I had ever made; and I had good reasons to be persuaded that the extraordinary induration would proceed in time through the whole mass.

SECTION

SECTION VIII.

Experiments made with a View to approximate the best Proportions of Lime Sand and Water, for Mortar.

IN reading over my notes, and examining the specimens of mortar which I had hitherto made, I perceived that those were the best which being made with common fresh lime, or with well burned lime, contained the least of it; that is one ounce of lime in six or more of sand; and finding this quantity of lime to be much less than is used in the common way of making mortar; and suspecting that as a wall may be the weaker for its containing too much mortar, which widens the joints, so mortar may be weakened by the introduction of more lime than is necessary to cement the grains of sand together; I thought another cause of the defect of common mortar opened to my view; and that it was advisable to determine by experiment, what is the best
 propor-

proportion of lime to sand, in making mortar in which lime water is used.

I MADE five parcels of mortar with my best stone lime recently flaked with lime water, and with the coarse Thames sand, in the following proportions by weight.

1.

| | | | |
|-------------------|---|---|---|
| Slaked lime | — | — | 1 |
| Sand | — | — | 4 |
| Lime water, q. f. | | | |

2.

| | | | |
|-------------------|---|---|---|
| Slaked lime | — | — | 1 |
| Sand | — | — | 5 |
| Lime water, q. f. | | | |

3.

| | | | |
|-------------------|---|---|---|
| Slaked lime | — | — | 1 |
| Sand | — | — | 6 |
| Lime water, q. f. | | | |

4.

| | | | |
|-------------------|---|---|---|
| Slaked lime | — | — | 1 |
| Sand | — | — | 7 |
| Lime water, q. f. | | | |

5. Slaked

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|-------------------|---|---|---|
| Slaked lime | — | — | 4 |
| Sand | — | — | 8 |
| Lime water, q. f. | | | |

THIS latter specimen was not sufficiently plastic for common use ; or as the workmen express themselves, it was too short. I further observed that the quantity of water required to make mortar to the proper temper, is greater as the quantity of lime is greater relatively to the quantity of sand.

I SPREAD these on tiles in the month of June, and exposed them to the air and the sun, which then was very hot,

As my former experience taught me to expect that some of these, in hasty drying, would crack considerably ; and as mortar, in building, is not liable to dry so quickly as these specimens ; in order to render the inferences from these experiments the more general, I made five other parcels of mortar in the same manner and exposed them in the same way, in every respect, except that the direct rays of the sun could not fall on them

or

or heat the pavement on which they stood. In three days I found this necessary, for the first of those which stood exposed to the sun cracked considerably, the second cracked less, the third shewed three or four very slender fissures visible only on a very close inspection, the fourth and fifth shewed no cracks at this time, nor in a month afterwards, when the fissures of the others were considerably enlarged.

OF the specimens kept in the shade and examined on the third day like the former, the first was cracked in divers parts, the second shewed two or three very slender cracks, the rest were not cracked in the least, and never cracked afterwards, although I was forced to remove them to the place where the others stood.

Thus it appeared in a very short time that an excess of lime disposes mortar to crack, and consequently injures it; that the highest proportion of lime to such sand, which may be used without incurring this inconvenience, depends on the circumstances in which the mortar is to be exposed; that no more than

one part of lime to seven of coarse sand ought to be used in mortar which is to dry quickly ; and less lime may not be used, because it does not render the mass sufficiently plastic for building or incrustation ; and that if a greater proportion of lime to such sand improves the mortar in any respect, it is to be used only where the mortar cannot dry so quickly as it did in the specimens exposed to the sun.

IN the course of nine months I clearly perceived that those specimens which stood in the shade for the first three days, were harder, and better in other respects, than those which were suddenly exposed to the sun, the comparison being made between the specimens which contained the same proportions of lime, and which cracked the least, or not at all : and of all the specimens, those were the best which contained one part of lime in seven of the sand : for those which contained less lime, and were too short whilst fresh, were more easily cut and broke, and were pervious to water ; and those which contained more lime, although they were closer in the grain, did not harden
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so soon or to so great a degree, even when they escaped cracking by lying in the shade to dry slowly.

I THEREFORE concluded that hasty drying injures mortar made in any proportions of such sand and the best lime; and that the best proportion is one of lime in seven of sand, whether the mortar is to be quickly dried or not.

I MUST observe however that these conclusions were made rather with a view to my future experiments, in which an approximation to the best proportions of lime and sand and the best treatment of the mortar would save a great deal of trouble, than to any general and invariable rule for making mortar.

I RESERVED it to be mentioned in this place, that I set apart four ounces of each of the foregoing specimens of mortar, and spread these portions severally on plates of thin window glass, to the thickness of a quarter of an inch or thereabouts; and I noted the weight of each plate with its specimen of mortar recently made.

THESE being equally exposed to the sun and weighed at different periods were found to lose weight in equal times nearly in the proportion of the quantity of lime or of water used in making them; and the smallest loss of weight when the specimens were perfectly dry and considerably hardened, was one-tenth of the weight of the same specimens recently made.

IN many former experiments I had observed, but reserved it to be mentioned in this place, that mortar which sets without cracking, whether this be owing to the due proportion of sand, or to the slow exhalation of the water from mortar containing less sand; never cracks afterwards, whatever other faults it may have: the specimens mentioned in this section, after a trial of eighteen months afforded the same observation.

By the setting of mortar, I understand that solidity which it acquires by mere drying, and which differs widely from the induration that takes place in time by other means which we shall presently consider.

SEEING then that the quantity of water in mortar is as the quantity of lime, that the fissures happen only in the drying or setting, that the danger of cracking is greater, not merely as the quantity of water is greater relatively to the sand, nor merely as the water is more expeditiously exhaled, but in a rate compounded of these; I inferred that mortar which is to be used where it must dry quickly, ought to be made as stiff as the purpose will admit, that is, with the smallest practicable quantity of water; and that mortar will not crack, although the lime be used in excessive quantity, provided it be made stiffer or to a thicker consistence than mortar usually is.

THIS inference was afterwards found to be true: for specimens made thus with one part of lime and only six of the sand, and others made with greater proportions of lime, but as stiff as they could be used, did not crack, in any exposure; but they had faults which will be hereafter noticed.

SECTION IX.

Theory of the Induration dependent on the Proportions of Lime and Sand in Mortar, and Observations on the bad Effects of the vulgar Proportions of these.

IT is sufficiently known that the aggregation of calcareous bodies, which burn to lime, or are chiefly composed of the matter of lime, is much weaker than that of the quartose; insomuch that the steel which easily cuts all calcareous stones or spars, is as easily cut by the siliceous; and all stones, or powders which are chosen for cutting or grinding steel, are found to have this effect by reason of their siliceous or quartose particles.

THIS being considered together with divers observations heretofore related, I reasoned in the subsequent manner.

As stones are cemented together in walls, by the mediation of mortar, so the grains of sand

sand or gravel are made to cohere and form a solid mass of mortar, by the intervention of lime.

By the bare inspection, as well as by the experienced induration, one part of lime paste appears sufficient to intercede the grains of seven of sand without interruption of continuity, and in drying to fill the spaces between them, or to attract matter enough for this purpose from the air.

IN this case the grains cohere at the smallest distances of them, and by means of the thinnest laminæ of calcareous matter; and such mortar is the stronger as it consists of the greater quantity of hard quartose bodies cohering by means of the smallest practicable quantity of softer and brittle calcareous strata; just in the same manner as a wall, built with porphyry and bad mortar, is, *cæteris paribus*, the stronger as the joints are made thinner: for all masses of such structure as mortar or cementitious walls, resist fracture and ruin, with powers of aggregation which are, not merely as the aggregation of the stones or bricks, nor barely as the aggregation of the softer cement, but in a ratio compounded of

these, and varying with circumstances which we need not attend to at present; and those masses therefore will resist the most, in which the stronger aggregates bear the greatest proportion to the weaker, so far as it is consistent with the continuity of them,

SECONDLY, The small stones which compose a heap of sand do not imbibe water: their volume is not encreased by wetting them nor lessened in drying; neither does a measure of wet sand contract sensibly in drying: this last I have repeatedly experienced. But small bits of lime are considerably increased in bulk by wetting them; and as the soft paste of lime contracts greatly in drying, it must crack in every part where the drying paste is prevented, by its adhesion to bodies or by other causes, from contracting uniformly and concentrically. As the contraction of mortar in drying, and its consequent cracking, depend on the lime paste, and not on the sand, they must take place in the greater degree, as the quantity of lime and water is greater, and they must be lessened or prevented by a due proportion of sand; which proportion experience shews to
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be seven parts of sand to one of lime. Thus we understand the causes of cracking, and how it happens that this defect is prevented by using less than the customary quantity of lime; and, although the lime should be used in excess, by using less than the usual quantity of water,

THIRDLY, The more perfect and expeditious setting and induration of mortar containing only one part of lime in seven of sand, than of mortar made with greater proportions of lime, may be deduced from several concurrent causes. Having less water in its composition, it dries sooner, and the calcarious matter crystalizing more quickly in it, gives it sooner that solidity which we express by the word setting. Having less lime in its composition, it is sooner saturated with the matter which the air presents, and which seems necessary to the induration of mortar; and in this saturation, the swelling of the lime is not so great as to push forth and derange the grains of sand after they have once been placed and in some degree cemented together.

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THIS latter inconvenience arising from the excess of lime, cannot easily happen in mortar compressed on all sides in massive buildings; but it manifestly occurs in the exterior parts of the joints in walls, where the mortar visibly swells and after swelling crumbles: it is likewise visible in the upper part of walls of modern construction, where the swelling is not prevented by a superincumbent weight. In these cases the joints become hollow; houses lately built look old or ruinous; and the bricks themselves, being bibulous, in such exposure soften and moulder, in consequence of the alternate wetting drying freezing and thawing; these being effectual agents in the dissolution of all bodies which freely imbibe moisture.

WITHOUT awaiting the event of those experiments which I have lately made on the great scale, and shall point out before I conclude this essay, we may on these grounds alone assure ourselves that the strength and duration of the calcareous incrustations composed of lime and sand, will be greater, as we depart further from the proportions of lime and sand commonly used, approaching
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to that of one part of lime to seven of sand; because the stucco which hardens the soonest must be the least injured, whilst it is new, by the beating rains, and various accidental impressions; because that which adheres most firmly to the other materials of buildings, and which acquires the greatest degree of induration, must contribute most to the strength of the walls, and best withstand the shocks, attrition, and other trials to which the stucco is exposed; because that which contains the greatest proportion of sand, is less liable to be injured by any saline matter with which the air is sometimes impregnated, as its calcareous matter is the better defended by the sand: but above all, because the stucco made with one part of lime and about seven of sand, is not disposed to crack: for incrustations in this climate perish sooner by reason of the fissures than of any other defect; because the water imbibed into the slenderest of them, as well as into those which appear on a cursory view, swells in the congelation, and dilates them; and frequent alternations of wetting and freezing, gradually widen them, until the stucco is bulged and torn from the walls.

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SECTION X.

Experiments on old Cements, authorizing the Proportion lately recommended of Lime and Sand.

TO discover the quantity of lime and sand originally used in any hard and old cement which I find by a previous analysis to consist of lime and sand or clean gravel, I break a pound of it into small fragments, but not into powder, and with diluted marine acid I dissolve and wash away the calcareous part from the gravel or sand. I measure the acidulous gas obtainable during the solution, and knowing the weight of any quantity of it in any temperature or weight of the aerial atmosphere, I subtract this weight of acidulous gas and that of the sand or gravel, from the whole weight of the mortar, and state the residuary weight as that of the lime originally employed; knowing that it could not have made so hard a cement, if it had not been so far burned as to retain very little acidulous gas. I did not adopt this method of examination before I had found it to exhibit
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the lime and sand of my oldest and hardest cements in the same proportions in which I had mixed them.

By this kind of analysis, and by other trials, I found that the quantity of lime in old cements made with clean sharp sand, and noted for their hardness, was much less than is now commonly used in mortar; and that in the hardest, it was very near to that which my experiments indicate to be the best.

By sharp sand I mean that whose grains are bounded by flat surfaces.

Thus I found the inferences made from my compositions to be authenticated by long experience, so far as they relate to the proportions of lime and such sand.

SECTION

SECTION XI.

Experiments and Observations shewing the Agency of acidulous Gas in the Induration of Mortar, and Circumstances which impede or promote it. Practical Inferences.

THE observations made on divers specimens of mortar, at different periods, led me early into the opinion that the setting of mortar depends chiefly on the exsiccation of it, but that the induration is principally owing to the accession of acidulous gas in certain circumstances, and not to the drying, as the workmen generally imagine. In order to place this opinion beyond a doubt, and to discover the circumstances which favour or impede this induration, I made the subsequent inquiries.

EXPERIMENT I.

I MADE mortar with seven parts of the Thames sand, one of the best flaked chalk lime and the necessary quantity of lime water, and forming a part of it into oval pieces,

I put these into a gallon bottle, which I stopped closely with a ground glass stopple waxed; and I noted the gross weight of the bottle and mortar, and placed it exposed to the sun. Having examined it frequently during the first month, I could perceive no alteration in the weight, nor any thing worth notice, except that some water exhaled out of the mortar, and condensed in bright drops on the sides and upper parts of the bottle. At divers times during six months afterwards I shook and weighed the bottle, and found the mortar quite soft and the weight of the whole unaltered.

EXPERIMENT 2.

ANOTHER portion of the same mortar was spread briskly, as soon as it was made, on oblong pieces of dry and warm tile, and these were immediately placed over a sand bath, where they were gradually heated to about an hundred of Farenheit for six hours, and then to an hundred and fifty for two hours more, when the mortar was dried thoroughly. I took particular notice of the solidity which it acquired in this hasty drying, and then put the pieces of tile with the adhering

hering mortar into a bottle closely stopped in the manner already described, marking the gross weight.

At the expiration of seven months, I found the whole unaltered in weight, and the mortar as easily cut or broken as it was when I put it into the bottle.

EXPERIMENT 3.

ANOTHER part of the same mortar was spread whilst fresh on a large tile, to the thickness of half an inch, and the tile was immediately placed in a tub, in which I put water to the depth of three inches over the mortar, and which I placed in the open air to receive the rain. At different times I broke the calcareous pellicle which formed on the water and defended it from the air, during the first fortnight : afterwards the wind and rain rendered this precaution unnecessary. In the course of six months, the mortar, instead of acquiring any solidity, was deprived of the greater part of its lime ; and what remained on the tile, was not much different from a layer of wet sand.

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ANOTHER portion of the same fresh mortar was spread on a board strewed with flaked lime to prevent adhesion, and placed in the open air, but sheltered from the sun. When this mortar became sufficiently solid, which was on the second day, I raised the pieces, which were about a quarter of an inch thick, from the board, and set them upright, fully exposed to the weather, which was about this time dry and warm. In seven weeks after this exposure they were indurated to a considerable degree. They resisted a cutting instrument nearly as much as Portland stone does, but not so well any force tending to break them across at once. I then placed them under water as I had done by the former portion of this mortar.

After they had lain in the water four months I examined them attentively and found them, if at all altered, to be rather softened than indurated further. I replaced them in the water, to be better satisfied about them; but by mistake, they were removed in my absence, and lost.

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E X P E R I M E N T 5.

SOON after the foregoing parcel of mortar was made, I prepared another in the same manner, and spread a part of it on a tile soaked in lime water, and placed the tile in the open air sheltered from the sun and rain. After it had stood a month in this situation, I placed it where it was sheltered only from the rain.

E X P E R I M E N T 6.

ANOTHER portion of the same mortar was spread fresh on a warm dry tile, which I placed over a sand bath, where the mortar was heated to about an hundred of Farenheit for six hours and then to an hundred and fifty for four hours more, at the expiration of which it was solid and perfectly dry. The next day I placed it in the open air, exposed to the sun, and the weather, which was dry and warm for a considerable time afterwards.

ON comparing these two last at the expiration of seven months, and again after six months more, I could easily perceive that
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the latter was inferior to the former; for it was much more easily cut and scaled from the tile and broken.

EXPERIMENT 7.

WITH mortar made, the day after I had made the former, of the same materials and in the same manner; and with new bricks, which I had heated almost to redness and suffered to cool to the temperature of my hands; I briskly erected a little wall half a brick thick, on a stone bench raised for the purpose and fully exposed to the weather.

EXPERIMENT 8.

ON the same day and with the like mortar, and with cold new bricks previously soaked in lime water, I erected another wall, equal to the former in dimensions, and placed in the same manner on a stone bench in the open air.

AFTER nine months, in pulling these walls to pieces and in divers comparisons of the cement of them, I found that the latter cement adhered better to the bricks and was

harder than the former, infomuch, that I had not a doubt about it.

EXPERIMENT 9.

IN a few days after I had made the experiment with the warm bricks, I considered the walls erected in variable weather, and the fence walls which are wetted frequently and deeply whilst new, by rain, or by moisture from the ground, and as often dried quickly; and I was desirous to learn the effect of such alterations of wetting and drying.

I THEREFORE spread mortar, made like those parcels lately mentioned, on a large tile soaked in lime water, and as often as it had dried, in fair weather, and generally at the interval of three days, I wetted it with rain water. In the course of nine months I found it was much less indurated than the specimen made in the same manner, and defended from the rain: it moreover grew green by means of a vegetation which took place on the surface of it, and which thrived the more as the mortar was frequently wetted, or the tile longer suffered to lie flat on the stone bench already mentioned.

I HAD often observed such a vegetation on mortar which I had made a few months before, especially when, in the summer season, I laid the tiles flat on the wooden border of a dust-hole, or when, for want of room to preserve the specimens in, I piled many of them together in a damp corner on the pavement: I likewise saw that where the vegetation took place, the induration did not proceed as it does elsewhere: on the contrary, semi-indurated mortar softened there.

ALL these being considered, I was satisfied that frequent wetting or constant moisture, together with exposure to air, injure mortar in a great degree, if it be not perfectly indurated by great age before it is exposed to such trials; and that the vegetation depends chiefly on moisture.

EXPERIMENT 10.

By the kind of analysis mentioned in the tenth section, I repeatedly examined the proportion of acidulous gas to the lime, in the hardest of the old cements which I had collected; and finding it in the best of them to be, at the lowest, in the proportion of three

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to five, I rate the quantity of acidulous gas imbibed by good mortar, during the induration of it, at sixty pounds at least, for every hundred pounds of lime.

EXPERIMENT II.

SUCH mortar as that of the first experiment of this section was formed into slender pieces, each an inch broad, a quarter of an inch thick, and three inches in length. These were placed in an airy passage, sheltered from the sun and rain, and were turned as soon as they could bear it without danger of cracking; they were then set upright and fully exposed on all sides to the air.

ON the fourth day I slid four of the pieces entire into a small wide-necked glass retort, which I set deep in a sand bath, with its nozzle immersed in quicksilver, which stood cool whilst the charge was gradually heated, in the course of forty-eight hours, to about seventy-five of Fahrenheit, which is under the temperature of incrustations of this kind exposed to the sun in summer; and in the course of forty eight-hours more was slowly heated to about an hundred of Fahrenheit, to which

which degree incrustations are frequently heated by the sun in summer. As the retort cooled I admitted the necessary quantity of air, and then left it, with the nozzle immersed deeply in the mercury, during three months. I then slid the pieces gently out of the retort, after having wiped away a few drops of water which adhered to the vessel in their way ; and immediately made the comparison which I shall presently mention.

CLOSE to the retort, and in a situation where the heat was equal to that described, or nearly so, I placed four other of the pieces above described, on the fourth day after they were made : I encompassed them with the sand, but secured a free access and even a circulation of air to them. When the sand bath was cooled, I put these pieces, which were thus perfectly dried, into a bottle which I stopped closely in the manner heretofore described.

ON the seventh day after the pieces were made, on the twenty-first, and at the expiration of three months, I examined four pieces taken from different quarters of the

remaining parcel, and found the quantity of acidulous gas which they yielded, to correspond with the degree of induration and the depth to which it had advanced in them respectively.

ON comparing and examining the pieces dried in the retort and kept three months in it; the pieces dried in the same heat and freely exposed to air during four days, but afterwards kept in a close vessel; and the pieces which dried and hardened in the free air, without being heated; I found that the first were friable in comparison with the second, and the last were by much the hardest and best,

As the second tenth and eleventh experiments, together with observations formerly made, shew that the induration peculiar to mortar, is not caused by exsiccation; that it is greater, as the calcareous matter of cements approaches nearer to be saturated with acidulous gas; that it is retarded or prevented, as the accession of acidulous gas is interrupted or obviated; we may conclude that this matter is a principal agent in the induration of calca-

calcareous cements and indispensibly necessary to it.

By observations formerly made, but especially by the comparison of the fifth and eight experiments of this section with the sixth and seventh, I learned that hasty drying prevents good mortar from ever acquiring the hardness which it otherwise would have; and that the more slowly the proper water of the mortar is exhaled or absorbed from it, in incrustations or brick-work, the more perfect will be the induration of it.

By the first third and ninth experiments of this section compared with the fourth, fifth and others, and by observations which led me to make these experiments; I discovered that mortar which is not suffered to dry, or which is supplied with moisture as fast as its proper water exhales, does not harden, or hardens only to a small degree by any accession of acidulous gas.

THE fourth experiment indicates that mortar, whose lime has not yet imbibed its complement

plement of acidulous gas, although the mass be considerably hardened, is liable to be injured by soaking in water, if it be pervious to water so freely as these thin pieces were.

ALL these experiments and observations conspire to point out the circumstances in which mortar becomes indurated the soonest and in the highest degree, and operates most effectually as a cement. To this end it must be suffered to dry gently and set; the exsiccation must be effected by temperate air and not accelerated by the heat of the sun or fire: It must not be wetted soon after it sets; and afterwards it ought to be protected from wet as much as possible, until it is compleatly indurated: the entry of acidulous gas must be prevented as much as possible, until the mortar is finally placed and quiescent: and then it must be as freely exposed to the open air as the work will admit, in order to supply acidulous gas, and enable it sooner to sustain the trials to which mortar is exposed in cementitious buildings and incrustations.

FROM these considerations we learn other causes, besides those already mentioned, of the speedy ruin of our modern buildings.

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THE mortar made with bad lime and a great excess of it, and debased in watering and long exposure, is used with dry bricks and not unfrequently with warm ones. These immediately imbibe or dissipate the water and not only induce the defect above noticed, but, as the cement approaches nearer to be dry, whilst it is still liable to be disturbed by the percussions of the workmen, render it more nearly equivalent to a mixture of sand and powdered chalk.

BUT to make strong work, the bricks ought to be soaked in lime water, and freed from the dust, which in common bricklaying, intercedes the brick and mortar in many parts. By this method the bricks would be rendered closer and harder; the cement, by setting slowly, would admit the motion which the bricks receive when the workman dresses them, without being impaired; and it would adhere and indurate more perfectly: the same advantages would attend the soaking of bibulous stones in lime water, and the use of grout; provided this were made with good lime sand and lime water.

IN plaistering, the workmen always brush away the dust and wet the wall on which they are to lay the cement, because it will not otherwise adhere. From what has been already said it is manifest that this ought to be done with lime water, and repeated as long as the wall is thirsty.

To perceive more clearly how much our slight buildings are weakened by the agitations and percussions to which they are exposed, first in erecting the walls and settling the timbers, and then in driving those wedges to which they fasten the wainscots cornishes and other ornaments, we must observe that the accession of acidulous gas to mortar, was found to contribute nothing to the strength of it, when it entered the composition before it was finally fixed in a quiescent state: and a little experience is sufficient to teach us, that the same matter which assists in the induration of mortar, never serves to repair the fissures, or solution of continuity between the bricks and cement, which happen after it is set. When mortar is set, and before it is indurated, it may easily be served from the
bricks

bricks and crumbled; and for want of softness it cannot bend into the fissures, or resume its former condition in any time. Therefore by heavy blows, and in wedging, our walls must be greatly weakened; and the more, as the houses are slight, quickly built, and hastily finished.

SECTION XII.

Experiments shewing the best Kinds and Mixtures of Sand, and the best Method of using the Lime Water, in making Mortar.

PURSUING the analogy intimated in the ninth section, I thought that as large stones with carvilinear faces, bedded in common mortar, do not form so strong a wall as they may when their interstices are filled with fitting stones together with the due quantity of mortar; so mortar made with sand, whose grains come near to be equal in size and globular, cannot be so strong at any period of induration, as that which is made with the same mixed with as much fine sand as can easily be received in its interstices, in order that the lime may cement the grains by the greater number and extent of contiguous surfaces. By this notion I was excited to make provision for a new series of experiments.

I CLEANSED a large quantity of the Thames sand, by washing it in streaming water, and
sorted

sorted it into three parcels: the coarsest, which I call the rubble, consisted of small pebbles, fragments of weathered shells, and grains of sand of divers sizes, which in washing had passed through a sieve whose apertures were one eighth of an inch square, but could not pass through a brass wired sieve, whose meshes were one sixteenth of an inch square, or rather larger: the next parcel, which I called fine sand, consisted of grains of divers sizes, which in washing passed through a finer sieve whose meshes were one thirty-second of an inch square: the third parcel consisted of grains the largest of which were washed through the coarsest sieve, and the smallest were retained, in washing, on the fine sieve: this I call coarse sand.

It is to be observed that the sand which can pass through a sieve, in washing, is considerably finer than that which may be sifted through the same sieve, when it is dry.

HAVING dried these parcels on a sand plate, and provided a narrow mouthed glass bottle capable of holding about two ounces troy of water, and a cylindrical glass vessel which contained

tained twelve of these measures, I found by repeated trials, that the large vessel, charged to the brim with my rubble, might be made to hold somewhat more than one additional measure of it, when the rubble was well packed, by striking the bottom of the vessel frequently against the table perpendicularly. Charging the same vessel with coarse sand, I could by the same treatment make it hold two thirds of the thirteenth measure: and twelve measures of fine sand were so far contracted in this motion of the vessel, that it could hold one measure and one fourth more, or thirteen and one fourth in all.

AFTER noting how far the interstitial spaces in each sized sand can be lessened by packing, I used water to shew what proportion these bear to the solids, in these different sands. I found that the thirteen measures of rubble which I stowed into the glass cylinder, could take in five measures of water, without any increase of bulk; or rather with a striking decrease of bulk: the twelve measures and two thirds of stowed coarse sand, imbibed four and one half of water, and yet decreased sensibly in bulk: the thirteen
measures

measures and one fourth of fine sand packed, could drink in only four measures of water ; but the diminution of bulk was more considerable than in either of the former ; for the sand and water together measured less by one seventieth than the packed sand alone.

WHEN sand was poured into the glass cylinder until it was filled, and water was added before the sand was packed, by a slight agitation of the vessel the sand contracted in a much greater degree than is above expressed. Upon the whole it seemed that water, by positing the grains, facilitates their sliding on each other to fit well and fill the spaces.

UNTIL I had made these experiments I did not well understand, how the beating of new mortar makes it much wetter, and more plastic withal, than it can be made with the same proportions of water and solids, by mere mixture. I now perceive that beating produces this effect by closing the interstices of the sand, and rendering a small quantity of lime paste as effectual towards filling them and holding the grains together to form a

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plastic mass, as a greater quantity is, in sand whose grains cannot fit each other so well.

SEEING that the interstitial spaces in sand are so greatly lessened by wetting it, I judged it expedient, for this reason alone, to expend all the water I should henceforward use in making mortar, in wetting the sand completely. I afterwards observed other advantages arising from this practice: for in filling the spaces with the fluid, the air is easily expelled, and the lime equably diffused in them by a little beating: but when the water is added to a mixture of lime powder and sand, the air is entangled in the lime paste, and cannot, without a great deal of beating, be totally pressed out of the plastic mass: I likewise found, that as an excess of water is injurious in mortar, this is an excellent method of regulating the quantity of water; for the portion of lime water which fills the spaces in sand, and can be held by capillary attraction in a flat heap of it, is precisely the quantity which makes well tempered mortar with one part of the best flaked lime and seven of the best sand.

As I found some difficulty in expelling the air bubbles out of the sand wetted in my deep cylindrical measure, even when I stirred up the mass with a slender instrument, I concluded that the spaces in sand are rather in a higher proportion to the solid substance of it, than they appeared in these trials: so that we may say they are at least one third and more of any measure of the fine sand, greater in coarse sand, and greatest in the rubble. Suspecting on another ground that these experiments did not shew the whole of the spaces in sand, because water tends to insinuate itself between the contiguous faces of the grains, and consequently to remove them asunder, even whilst it arranges them; I attempted to ascertain the proportion of these spaces to the solids, by another method founded on this supposition, that the measured portion of sand which weighs the most, has the smallest quantity of interstitial space.

By the experiment, I found that a well packed measure of the rubble weighed twenty ounces three pennyweights: the like measure of the coarse sand packed, weighed twenty one ounces eighteen pennyweights:

and the same quantity, by measure, of the fine sand, weighed twenty three ounces two pennyweights and twelve grains.

THIS trial corresponds sufficiently with the former in shewing, that the sum of the spaces in the rubble, is much greater than that of the coarse sand, and that the spaces in this are larger in the sum, than those of fine sand.

IN order to learn whether this proportion is maintained in all kinds of sand, I tried by water and by weight in the foregoing manner, a great number of sands used in London; such as the coarsest glass-grinder's sand, Hampstead-sand, Lynn-sand, fine house-sand &c.

THE result of these experiments taught me that the spaces are always smaller as the sand is finer, provided the comparison be made between the sorted fine part and the coarsest part of any kind of sand: but this does not hold true in the comparison of fine sand and coarse sand of different districts.

ON examining the several specimens of sand with a lens, I perceived that, in some, the grains, however different in figure, were bounded by flat faces meeting each other in angles; whilst in others, the faces were generally rounded, and the figure such as the foregoing grains would be reduced to by grinding off their angles. The first kind I call sharp sand, the other round sand. Then taking into consideration the measurement already described, together with the sharpness or roundness of the sand, I found that the spaces are, in different kinds of sand, as the size and roundness of them compounded; but they do not appear to be smaller in any kind of sand that I have seen, than in our fine parcel of Thames sand; which I think is owing to its being sharper than any of the finer sands which I had compared it with. The measure which contained twenty-three ounces two pennyweights twelve grains of the fine Thames sand, contained only twenty-two ounces ten pennyweights of the Lynn sand, which is a great deal finer, but rounder.

HAVING thus found the kind of sand which, by reason of the size and figure of the

grains, has the smallest interstitial space ; I next endeavoured to ascertain the mixture of coarse and fine sand, which lessens this space in the greatest degree, which therefore requires the less lime to cement the grains together, and for the reasons already mentioned, promises to make the hardest and most durable cement.

I FOUND that nine measures of the shingle, and nine measures of the fine sand, both well packed, measured when mixed and stowed closely sixteen measures and one-eighth : that eighteen measures of the shingle and nine of the fine sand tried in the same way, measured twenty-four : and that on mixing the shingle and fine sand in various proportions, nine measures of shingle took, into its interstices, one measure and one half of the fine sand, without any increase of bulk,

I NEXT learned that nine measures of the coarse sand and nine of the fine, measured in the like manner seventeen and a half : that eighteen such measures of coarse sand well mixed with nine of the fine sand, measured twenty-six : and that on mixing these sands
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in various proportions, eighteen measures of the coarse sand took into its interstices one measure of the fine sand, without any increase of bulk.

LASTLY I found that eighteen such measures of the coarse sand and nine of Lynn sand, which is much finer grained than the foregoing, measured twenty-four when well mixed and stowed : and that on mixing them in various other proportions, nine measures of the coarse sand took into its interstices one and a half of the Lynn sand.

By these and a variety of similar experiments made on different sands, I found that the quantity of fine sand taken into the interstices of a coarse sand, was the greater without increase of bulk, as the grains of the coarse differed more from those of the fine in bulk, provided the diameters of the grains of coarse sand did not in general exceed those of the fine, in a proportion greater than five to one ; that the greatest quantity of fine sand, which could be taken into the interstices of coarse sand, was one-sixth of the bulk of the coarse sand ; and that in general the

mixture of six measures of coarse sand with one of the finest sand, reduced the sum of the interstitial spaces to nearly one half of the quantity of them in coarse only, or in fine Thames sand or rubble only.

INSTRUCTED by these observations I proceeded to the following experiments, in order to learn the advantages or defects attending each kind of sand, and how far my expectations from the art of lessening the spaces, were well founded,

I MADE several parcels of mortar with my chalk lime lime water and rubble in different proportions; the quantity of lime being in one a fourth of that of the rubble, in another only one-seventh, and in the others intermediate: I made other parcels of mortar with my chalk lime, lime water, and the coarse sand; and others with this lime, lime-water and the fine Thames sand, in the last mentioned proportions,

I NEXT made a great variety of specimens of mortar; some of which consisted of rubble and coarse sand mixed in different proportions,

portions, wetted with lime-water, and blended with one-fourth or one-seventh or intermediate quantities of lime: others were composed of similar mixtures of rubble and fine sand with lime and lime water; and others consisted of rubble coarse sand and fine sand mixed in different proportions, wetted with lime water, and beat up with the different quantities of lime lately mentioned.

I SPREAD a part of each of these specimens of mortar, as soon as it was made, on a tile soaked in lime water, half an inch thick in some places, and much thinner in others: I placed the remainder of it, formed into oblong pieces of about an inch diameter, on the part of the tile which was not covered with mortar; and I set all the tiles numerically marked, in the situation formerly described, where they were equally exposed to the weather: this was done in May, 1777: during the succeeding twelve months I examined each specimen, and noted my observations, the most useful of which I shall endeavour to relate in a few words.

THE specimens containing rubble and lime mixed in any proportion greater than five to one, were not fat enough, when fresh, to be conveniently used in building or stuccoing : but none of them, not excepting those which contained the greater quantities of lime, cracked in drying. Those which had the smaller quantities of lime in them, were very rough on the surface, coarse in the grain, spongy, and easily broken : they shewed a defect of lime, because those which contained more lime were not so bad in these respects. By all of them it appeared that whenever such rubble must be used, for want of sand or finer gravel, the lime mixed with it must not be less than one-fifth of the quantity of rubble.

OF the specimens consisting of coarse sand and lime, those which had the smaller quantities of lime were too short for common use, and could not be made to assume a close and smooth surface, whilst fresh ; but in drying and hardening, they were in every respect preferable to the cements made with rubble and lime, in the same proportions : and of the same specimens, those were the best which contained

contained one part of lime in five of sand; the others containing less lime being faulty like those made with rubble, and those in which the lime was mixed in much greater quantity, having the faults often observed to attend the excess of lime.

THE specimens which consisted of fine sand and lime, were in general better than the foregoing: and that particularly which contained one of lime in six and an half of sand, was in all respects much better than those made with the same or any other quantities of rubble and lime, or coarse sand and lime. The specimen which was formed with seven parts of fine sand, and one of lime was not so compact and hard as that last mentioned. The comparison of these two shewed that seven of sand are too much for one part of lime, when the sand is fine and unmixed with coarse grains. The specimen made with four parts of fine sand, and one of lime had the noted faults attending the excess of lime; for it cracked in drying, and was sensibly injured in the winter, by those alternations of drying, wetting, freezing, and thawing, formerly noticed.

ON

ON divers comparisons of those portion of mortar made of fine sand and lime, with the former, I was persuaded that a better cement can be composed with such sand as I call fine, than with a coarser sand, whose grains are all larger than any of those in my fine sand; provided the coarser sand be not much sharper than all that I have yet seen. If my experiments had been made in slow succession, this last observation would have led me to imagine that mortar will be found the better as the sand is finer.

OF the observations made on the parcels of mortar consisting of mixed sands and lime, those which follow are the most pertinent to our present enquiry,

THE specimens made with mixtures of rubble, coarse sand and different quantities of lime, resembled those made with rubble and lime in similar proportions, when the rubble was predominant; and resembled those made with coarse sand and lime, in similar proportions, when the coarse sand was predominant; and I could perceive

no

no advantage derived from the mixture of rubble and coarse sand, except that the cement was somewhat better as the quantity of rubble was less, relatively to the quantity of sand and lime: but none of these specimens were in any respect so good as those made with fine sand only.

Of the specimens made with rubble and fine sand, that was the best in which the fine sand was twice the quantity of the rubble. But I could not perceive that any of these specimens were preferable to those made with the like quantities of fine sand and lime; or that any considerable advantage is gained by the mixture of rubble and fine sand.

Of the specimens made of coarse sand fine sand and lime, those were manifestly the best, which consisted of four parts of coarse sand, three of fine, and one part or a little more of lime: for, whilst fresh, they were more plastic than the others, and were easily made to assume a smooth surface; they were not disposed to crack in this method of drying; they were not at all injured by wet or freezing or thawing; they were pretty close in the grain; and they

they grew so hard, in the course of nine or ten months, as to resist the chisel, or any force tending to break the oblong pieces, much more powerfully than any of the specimens lately mentioned. I noted them as the best specimens of mortar that I had ever made; and one part of lime, in four of coarse, and three of fine sand, to be a better proportion than any other of the sands and lime, for incrustations.

Of the various specimens of mortar made with mixtures of the rubble, coarse sand and fine sand, those were the best, in which the fine sand was equal or nearly equal in quantity to the rubble and coarse sand; in which the rubble was not much more than one seventh part of the quantity of both sands; and in which the weight of the lime was one seventh of the weight of the sand and rubble, or a little more: But these specimens, when fresh, were less plastic, and less capable of assuming a smooth surface under the trowel, as the quantity of rubble was greater; and I could not find they were preferable in any particular to those respectively which were made with similar quantities of lime and the mixtures of coarse and fine sand lately commended.

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Upon the strictest comparison, I concluded, that one part of rubble in three of coarse and three of fine sand, makes as good mortar with lime, as can be made with the sand and lime without rubble, for any purpose which does not require a finer cement; but there is no advantage gained by the use of rubble where the coarse and fine sand can be had equally cheap, unless a rough surface be required.

IN stuccoing walls the rubble promised to be useful in pointing and in the first coat; because a roughness of this coat makes the finer exterior coat adhere more firmly.

IN the review of all these specimens it appeared, that the quantity of lime, which forms a mass somewhat plastic with sand and water, is the smallest quantity necessary for making the best mortar which such sand can afford; and that any further quantity of lime is useless in the coarser sands, and injurious in the finer: that the necessary plasticity is induced by the smaller quantities of lime, as the interstices of the sand are smaller in the sum, and as the grains fit each other the better in consequence of the due mixture of coarse and
fine

fine sands : but that the lessening of the interstitial spaces, by the mixture of fine sand with the coarse, does not enable us to lessen the quantity of lime so far as might be expected in consequence of our notions of the spaces measured by water. It seems that the grains of fine sand are held asunder by the lime paste, to a greater distance than they are by water ; and that the reason, why the finer sand requires more lime than the coarser and mixed sand, is, that the spaces, which are more numerous in fine sand than in the coarse, are more augmented in the whole quantity of them, by the particles of lime, which intercede alike the coarse and the fine grains.

SECTION XIII.

Experiments shewing the Effects of finest Sand and quartose Powder, in Mortar: Observations on the finest calcareous cements: Practical Precepts.

THE last mentioned notion led me to suspect, soon after the foregoing experiments were made, that, although the fine Thames sand made better mortar than the coarse sand or the rubble afforded, the mortar will not always be the better as the sand is finer, however sharp it be. I therefore procured a large quantity of the very fine pit-sand used in London under the name of house-sand: I washed away the clay with which it abounds, and dried it: viewing it, when thus cleansed, with a lens, I estimated the size of the grains to be, at the medium of the largest and smallest, about one ninth part of that of my fine Thames sand: this I call finest sand. At the same time I was favoured, by my neighbour Mr. Bentley the ingenious manufacturer of the ornamental Staffordshire ware, with the

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necessary

necessary quantity of the fine powder of calcined flints, which is prepared for his manufactory.

WITH divers mixtures of these with lime water and lime, in a variety of proportions; and with each and both of these, blended with coarse and fine sand, lime and lime water in similar proportions; I made a great number of specimens of mortar, which I tried in the manner already described; and noting my observations on them, I found the following to be the most eligible for the concise recital intended in this essay.

MORTAR containing the quantity of lime necessary to the plasticity and other desirable properties of it, or a greater quantity of lime, is the more liable to crack in drying, as the sand of it is finer.

MORTAR made with this finest sand and lime, does not grow so hard, or resist fracture so forcibly, as that made with my fine Thames sand and lime, in the same proportions, or any others nearest to these. But the former mortar, when composed of about six
parts

parts of sand, one of lime, and the necessary quantity of lime water, and slowly dried, becomes much harder than any of the common calcareous stuccos, used by plaisterers.

MORTAR composed of lime, my fine Thames sand, and the finest sand, is the worse as the quantity of finest sand is greater: and this holds true in every tried proportion of the sands and lime.

MORTAR consisting of lime, coarse Thames sand, fine Thames sand, and finest sand, is the worse as the quantity of this last is the greater, when the comparison is made between it and the cement made with the same quantities of lime and the best mixture of coarse and fine Thames sand.

MORTAR made with flint-powder, lime and lime water, in any proportion, is more liable to crack in drying, than mortar composed of any sand and lime: it is moreover incapable of hardening to so great a degree; whether the hardness be tried with a chizel, or by breaking it across. But mortar made with about five parts of flint-powder, one of

lime, and the necessary quantity of lime water, is nevertheless preferable to any stucco now used in inside work, for the finishing coat; because it has a more lively whiteness, and assumes a finer surface, which I think might be made to imitate that of marble: It requires however to be dried very slowly.

MORTAR made with coarse Thames sand, fine Thames sand, flint-powder and lime; or with fine Thames sand, finest sand, flint-powder and lime; or with the finest sand, flint-powder and lime; is the worse, as the quantity of flint-powder is greater, relatively to that of the sand.

UPON the whole it appeared, that the finest sand is injurious in mortar which is exposed to the weather, and that flint-powder is still worse: but that this last may be advantageously used in composing stucco for inside work, in which, a fine texture, pleasing colour, and smooth surface, are preferred before extreme hardness; and in which the drying may be regulated so as to prevent the incrustation from cracking.

INSTEAD

INSTEAD of resting satisfied with the bare discovery of the fact, that very fine sand, or quartose powder, is incapable of making so good a cement as may be formed with coarser sand, although fine Thames sand and lime make a better cement than can be composed with the coarse sand and lime; and that the mixture of very fine sand, or siliceous powder, with the Thames sand, is rather injurious than useful, although the mixture of the fine with the coarse Thames sand, is better for mortar, than either of them unmixed; I took a great deal of pains to learn the cause of this, in order to confirm or correct the foregoing notions, and render the precepts which flow from this fact, the more satisfactory.

By sorting my finest sand into divers parcels, in sifting it through different sieves; by measuring the meshes of these; and by viewing the grains of each parcel ranked closely on a scale; I perceived, more clearly than I had done before, the roundness of this sand: I moreover found that the grains of the coarsest parcel were, at a medium of their respective bulks, upwards of sixteen

times larger than those of the finest parcel, the grains of the other parcels being of divers intermediate sizes. As this sand therefore has every advantage attainable by the mixture of coarse and fine grains, and every disadvantage resulting from the smallness and roundness of its grains, I learned the reason why the defects attending such fine round sand in mortar, are not corrected by any mixture of coarse sand. How these defects are induced by the finest sand and flint-powder, we may conceive in the following manner.

HAVING already shewn how the roundness of sand tends to render the mortar made with it defective, I may, without any further illustration of this matter, reckon on this figure of the grains of finest sand, as one cause of the imperfection of the mortar in which it is used.

THERE is nothing to prevent the laminæ of lime paste, which intercede the grains of finest sand, from being as thick, in the mass of mortar made with it, as they are in mortar made with coarser sand; but they are likely to be thicker in general, as the faces of the
finer

finer grains are rounder: The number and extent, moreover, of these laminæ, must be greater, in the sum, in the finest sand than in the coarser: and it is for these reasons, that more lime paste is required to make mortar with the former than with the latter; since the mortar is not formed, until the paste envelopes every grain, and fills the interstices. In this view of the subject, we discover another cause of the defect lately mentioned. If we use lime with a sparing hand, it will not extend between all the grains or fill the spaces; we find the mortar too short whilst fresh; and it is as defective in strength, when indurated, as it is deficient of the cementing matter. When we use the necessary quantity of lime, the calcareous matter bears a greater proportion to the quartose grains, in this finest mortar, than in the coarser; and this renders the former defective, according to the principles of aggregation already expressed.

A THIRD cause of the imperfection of mortar, made with finest sand, or containing a large quantity of it, appears, on the consideration of the quantity of lime. We have repeatedly seen that mortar contracts the more

in drying, and is the more apt to crack, as it contains a greater quantity of lime paste: and as the finest sand requires an extraordinary quantity of the paste to form it into mortar, the aggregation of such a cement is likely to be impaired by fissures, although they do not always appear, by reason of their smallness.

OTHER causes, of the experienced imperfection of fine mortar, might be added, which have no relation to the figure of the grains of sand or the quantity of calcareous matter; but to avoid an excess of theory, I forbear to mention them, and shall only add a conjecture concerning the finer cements.

WHEN a cementious mass, like mortar, is cut with an edged instrument, or broken across, we may observe that the fracture happens in the shortest line, along the laminæ of the weaker cementing matter, and seldom or never in the shorter right line passing thro' the harder grains and the cement alternately, although the impressed force tend to cause the solution of continuity in the shortest, or in a right line. By the principles of mechanics,
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the resistance to such forces is greater, *cæteris paribus*, as the line of fracture is longer, whether it be straight, or winding in any course: and it is for this reason, that a wall built with very large square stones, is less liable to crack, although the foundation should fail near one extremity of it, than a brick wall built with the same kind of cement on the like ground; or that a wall, whose bricks are jointed in the present fashion, is more secure from cracking, than that which should be built, on the like infirm ground, with the same kind of mortar and bricks standing over each other, not jointed, but with their sides and ends flushed, as the workmen express it.

As cements are cut and broken in the direction of the cement, and not in the shorter line; as the cracks in ill-founded walls run winding along the joints, instead of going in the shortest course through the bricks and joints alternately; and as the resistance of such cementitious masses, estimated by mechanical theory, is greater, as the line of fracture is necessarily elongated by the stronger aggregation of certain parts of them; I am inclined to think that calcareous cements made with
lime

lime and quartose matter, will always be found weaker, under the trial by the chizel or by fracture, as the quartose sand or powder is finer; because the line of fracture, which takes the course of the cementing matter, is shorter, in any equal depth of such masses, as the hard quartose grains are finer and rounder.

As flint-powder consists of exceedingly fine grains of silicious stone worn to roundness in the grinding, what has been said of the finest sand is sufficient to shew, why the cements, which contain flint-powder, are the worst of all those we have mentioned.

THE customary method of washing sand, even for stucco which is to be exposed to the weather, consists in passing it through a sieve, by a circular horizontal motion of it, in a tub filled with water, which flows over, and carries away with it any light matter which can be long suspended in water, as fast as the sand runs through the sieve into the vessel. But this process is inadequate to our views; because the finest sand subsides along with the best, and these, in the precipitation

cipitation, entangle and carry down with them a great deal of finer powder or dirt. Where such a method must be pursued, for want of other utensils, or through the scarcity of water, the sand ought to be agitated again in small parcels, with a part of the water which has cleared by subsidence; and immediately after the agitation, the muddy water ought to be poured off, before the light parts have time to subside in it. But the useful part of the sand is more effectually freed from the finer and noxious parts, by sifting it in streaming water, whose current is to be so managed, that it shall carry away the mud and the sand which is too fine, whilst the better part subsides in a proper receptacle. This art may be gathered from the practice of the Cornish miners, in washing their pounded ores, better than from any written precepts.

IN the subsequent pages I propose to shew the integrant parts of gravel, and their several properties in mortar: for my present purpose it will be sufficient to observe, that the gravel commonly employed in building consists chiefly, after it is skreened, of rubble,
coarse

coarse sand, fine sand, and finest sand, similar to those used in our experiments. This is obvious on the bare inspection of it, and leads us to discover another cause of the weakness of our modern cements, in the composition of which, no other precaution is used, respecting the gravel, except to separate the stones and coarsest rubble from it, by skreening.

WHEN it happens that the skreened gravel contains more than a certain quantity of rubble, relatively to that of coarse and fine sand similar to those described, the mortar made with it must, according to our experiments, be defective. It will be so likewise, whenever the coarse sand of it predominates over the fine sand, to a greater degree than that which was found consistent with the perfection of mortar: and when the quantity of finest sand happens to be considerable in gravel, the mortar made with it must be faulty in a greater degree. Now supposing the gravel to be freed, by the skreening, from every thing more injurious than finest sand and quartzose powder, we perceive that the artist, who is ignorant of the advantages of
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fizing his gravel, and uses it in its native state, as chance presents it, has the odds greatly against his making good mortar, although he may sometimes do it, without knowing the reason, as we shall find hereafter: for his chance is, that the native gravel shall consist of coarse and fine sand mixed in the proportion of 4 to 3, or of the rubble, coarse and fine sand mixed in the proportions above recommended; and that it shall contain little or no sand like our finest sand: but the chances against him are as numerous as there are other distant proportions of rubble coarse and fine sand in gravel, and as the kinds of gravel used are, which contain the finest sand or still finer quartose grains, in efficient quantity.

IN great cities, where gravel cannot be procured so cheap as the rubbish of old walls, which the workmen lay in the streets to be ground to powder by the passing carriages, they use this rubbish skreened, in the place of sand or gravel, in making mortar. It consists of the gross powder of bricks, and of mortar indurated, as much as bad mortar can be, by time; and some builders affirm that it is
better

better than sand or gravel, for mortar. It is certainly eligible when the price is chiefly considered; in any other view, it is not so. From my past experience I judged the calcareous powder of an old cement, and that of the bricks, to be a brittle perishable and weak substitute for grains of sand; and the quantity of dust in such ground rubbish, to be highly injurious: but as the opinion of the workmen was against me, I made some trials of it.

I FOUND that less lime was required to make fat mortar with this ground rubbish, than with my best mixtures of sand; which is no small recommendation of it in certain jobs, and is owing, in my opinion, to the ground calcareous part, which, so far as it is finely powdered, is equivalent to whiting: but the mortar made with the rubbish appeared, in every stage of induration, and in every comparison except that of the plasticity, to be greatly inferior to that made with mixed sand and lime, in the same proportions.

IF the workmen would confine their opinion to the comparison of such rubbish-mor-
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tar, with that in which clayey gravel is used, or with the cements made with the ashes and ordure of the town, dug out in preparing foundations of houses, in those places which were formerly receptacles of such matter, they might maintain it on divers grounds which will be examined hereafter; but otherwise it is erroneous.

SECTION XIV.

*Experiments made on a larger Scale with our best
Mixture of Sands Lime Water and Lime.*

IN the spring and summer of the year 1778, I repeated a great number of the foregoing experiments, particularly those which exhibit mortar in the improved state to which I had brought it; and finding my former observations to be true, when the circumstances were not varied, I resolved to try my best cements in larger quantity and in other circumstances. I applied them in the way of stucco, on the brick walls of houses, in different aspects, but chiefly in that of the meridian sun; covering a square yard at least with each specimen, after I had repeatedly wetted the wall with lime water.

By these trials I found that mortar, made with four parts of coarse sand and three of fine wetted with lime water and beaten up with one of my lime flaked with lime water, although

though it could be easily spread on a horizontal plane, or used in building with bricks, was rather too short for plaistering on the perpendicular surface of a wall. It might however be laid on, in small successive portions, by a dexterous management of the trowel, and especially by sliding the instrument on it upwards.

WHEN the weather continued temperate and dry for eight or ten days after the incrustation was made, and no great quantity of rain fell for three or four weeks afterwards, this stucco answered my expectations; for it did not crack in the least, and in three months was almost as hard as Portland stone, at the surface, where the induration first takes place for the reasons formerly mentioned; but it was too coarse to represent a fine grained stone.

HAVING made two pieces of incrustation of this kind, on the same wall, and knowing that calcareous cements cannot harden so soon as it is necessary in outside stuccoing, unless they be pervious to acidulous gas, in which case they may drink in water likewise, I

frequently wetted one of the pieces, in about three months after it was formed, with lime water, expecting that the calcareous matter of it would crystallize in the cement and render it closer and harder. I was not disappointed; for in the course of a month I found this piece of stucco harder and closer than the former, and at the surface, as much superior in these particulars, to Portland stone, as the other was inferior to it. I have since found that lime water has not this effect, if the incrustation be wetted with it, before it is quite dry and indurated slowly, to vie with Portland stone in that kind of strength which is tried by grinding Portland stone on it, or scraping it with a chisel; for any other trial of incrustations is unfair, until the induration has proceeded equally through the whole mass.

WHEN the incrustations made of the same cement, were wetted by rain, in two or three days, or sooner after they were applied, and especially when the wind blew the rain forcibly upon them, they were sensibly injured, for they never afterwards looked or hardened so well as the former specimens of stucco.

IN these particulars the large incrustations agreed with those made on tiles. But the same agreement did not appear in the incrustations which I had made with the same composition, on a wall which fronted the meridian sun, at a time when the weather was very hot; for these shewed a few slender cracks in the course of three days. When in the same situation and weather, and on a coarse stucco of this kind, I spread, in about two hours after it was laid on, a thinner coat of cement made with finer sand, in order to represent a finer grained stone, the incrustation consisting of these two layers, cracked more than the former.

AFTER many repetitions of these experiments, in the hottest weather, with the same event, I perceived that the trials of such cement on tiles, are not so severe as those to which they may be exposed sometimes in incrustations on walls. In this latter case, the stucco is very unequal in thickness; for in the hollow joints and depressions of the bricks, it is near an inch thick, when over the prominences it has not more than one-eighth of this thickness; and as it dries soonest in the thin parts,

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the unequal contraction seems to be the cause of those cracks, which would not happen to the same cement laid on the flat surface of a tile: it seems moreover that such a composition may more easily contract in drying, without cracking, as the crust is made narrower or less extensive. But I impute the cracking chiefly to the foregoing unequal contraction accelerated not only by the heat of the sun and the wall, but by the thirsty bricks; for if we form our judgment according to the quicker or slower progress of the exsiccation, and the stiffness which the cement acquires in the act of spreading it on the brick wall, the wetting of this last superficially with lime water, is not equivalent to steeping the tiles for a few minutes in the same liquor.

WHEN, with the view of preventing fissures, I stuccoed a part of the same wall wetted with lime-water with cement containing the mixed sands and lime in the proportion of fifteen to two, in the same kind of weather, I found the difficulty and waste, in applying it, greater than in the former instances, and that it was defective in strength and closeness, for want of lime, although it
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did not crack. When, through distrust of my former experiments, I used more than one-seventh of lime, the cracks were still larger and more numerous.

To guard a recent incrustation from the rain, and to secure it from cracking in the circumstances last described, I proposed the expedient of hanging sail cloth on the cornices and scaffolding : but the expence of this measure, and the danger of it in windy weather, were strong objections.

EMBARRASSED by this unexpected difficulty, I resolved to change my ground, and try what might be done by a new series of experiments, in which I intended to use every known cheap substance, whether it could be reasonably supposed to have any considerable effect towards securing a recent incrustation against the above-mentioned impressions of rain or hot weather, or could be suspected of rendering the stucco defective. I prosecuted this enquiry with great alacrity, because I was certain that, although I should fail in the attempt towards improvement, I should learn how in future to avoid those

things, which being natively blended in certain kinds of lime stone sand or water, tend to render the mortar made with them faulty. I had already conceived a notion, which I shall submit to my reader before I conclude, concerning the excellence of some antient cements; but lest I should be misled by it, I proceeded, in all the experiments which I am to relate, on the supposition that this excellence is owing to some matter, accidentally introduced in the materials which the Antients found in the districts contiguous to their most durable cementious works, or designedly blended with their mortar.

SECTION

SECTION XV.

Experiments shewing the integrant Parts of Gravel, the Choice and Preparation of it ; and the Effects of Clay, Fuller's Earth, and Terras, in Mortar.

ON inspecting different kinds of gravel used in London and in divers parts of England, in making mortar, I observed that they all contained some clay ; and that this was generally coloured with martial matter. In consideration of the frequency of this matter in mortar, I made it the first subject of my present enquiry.

By the art already described, I sorted three bushels of skreened gravel dug up near Portland Place in Marybone parish, into five parcels ; one equivalent to our rubble, another to coarse sand, another to our fine Thames sand, another to our finest sand ; and the remainder was set apart as clay or bolar earth. I dried all these, and reduced the lumps of clay to an impalpable powder.

HAVING treated divers other specimens of gravel in the same manner, I found that gravel, freed from the larger pebbles by skreening, may generally be considered as a native mixture of rubble, sand, and clay ; and that when the clay is washed out, the residuary parts of the different kinds of gravel, differ in size, sharpness, colour and hardness ; those being the hardest which consist chiefly of quartose matter. Judging of gravel according to the precepts derived from my trials of sand, I rank that dug in Marybone amongst the better kinds of gravel, and used no other in' mortar.

AFTER a great number of trials of cements made with my best chalk-lime, lime-water and the gravel, or certain parts of the gravel, and applied on tiles and on a wall, I found that those made with the coarse and fine sand of the gravel, separated from the rest of it, and mixed in their native proportions, were the best ; that those made with the rubble coarse sand and fine sand mixed in their original proportions, but containing no other part of the gravel, were the next in hardness and the other desirable qualities ;
that

that those containing all the parts of the gravel except the clay, in their native proportions, differed in nothing, that I could discover, from these last, for the finest sand of this gravel was not a fiftieth part of the mass of it; that those containing the rubble sands and clay in the same proportions, and those made with the unwashed gravel, appeared on a close examination to be the worst of all these: and those containing the native unwashed gravel mixed with twice its proper quantity of the clay of such gravel, shewed most clearly that clay is highly injurious, by disposing the mortar to crack in drying, to soften in wet weather, and to moulder when the quantity of clay is one-eighth of that of the sand; but in much smaller quantities, it only prevents the cement from acquiring the hardness peculiar to good mortar, and consequently disposes it to perish in a few years.

WITH my best mixtures of Thames sands lime water and lime, I blended fine fat tobacco-pipe clay, in different proportions, and exposing these specimens, I perceived that the effect of clay is greater as it is purer and fatter.

ter. The specimens in which the quantity of fat clay was one-seventh or one-eighth of that of the sands, mouldered early in the winter like marle.

THESE appearances were not altogether unexpected : for in experiments formerly made with a view to the improvement of fire-vessels, I had observed that clay adheres but weakly to any hard bodies, however slowly it is dried on them, and that masses composed of clay and sand in divers proportions, never acquired any considerable hardness by the mere drying and exposure to air : It was therefore not likely that clay should add to the strength of mortar ; but as dried clay greedily imbibes water and swells with it, and in drying contracts greatly and cracks, if any thing prevent it from contracting equally ; and as marle stones, which consist of clay and calcareous earth, moulder in the weather ; it was to be expected that clay would be hurtful.

THESE experiments point out another cause of the defects of the common mortar, and shew that the gravel or pit-sand to be used in
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any valuable building, ought to be freed from the clay by washing, which will be found a very cheap operation, even in cities, if the water which carries off the clay, be directed into a place where it may be depurated by subsidence, for repeated use: they likewise direct us in the examination and choice of these, and shew that the viler kinds may be made equivalent to our best mixture of Thames sand, or nearly so, by washing and sorting, and then rejecting the excess of rubble or fine sand.

I MUST observe however that some kinds of gravel cannot be made fit for mortar by this process: for the grains of them, which resemble those of rubble and coarse sand, consist of smaller grains cemented by clay, which is so far indurated that it cannot diffuse itself in the water speedily.

FULLERS EARTH tried in the same manner was found to operate in the mortar like clay, in every respect, as I might have presumed, except that the former was less injurious than the clay, when the quantities of them were equal.

TERRAS,

TERRAS, which is a volcanic production consisting chiefly of clay and calx of iron indurated together, when it was ground to an impalpable powder, produced the effects of fuller's earth, in mortar, the more sensibly as it approached nearer to be one-seventh of the quantity of sand. The coarser powder of terras had less effect.

A MORTAR made of terras powder and lime was used in water fences by the Romans, and has been generally employed in such structures ever since their time. It is preferred before any other, for this use, because it sets quickly, and then is impenetrable to water : whence some people hastily conclude that it is the best kind of mortar for any purpose. But by experience I know that mortar made of lime and terras powder, whether coarse or fine, will not grow so hard as mortar made with lime and sand, nor endure the weather so well ; but on the contrary is apt to crack and perish quickly in the open air. The efficacy of it in water fences is experienced only where it is always kept wet, and seems to depend on the property which the powder of terras has, in common with other
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indurated argillaceous bodies, and especially the boles, but in a higher degree, of expediting the crystallization of the calcareous matter, by imbibing the water in which it is diffused in the mortar, and of swelling, during this absorption, so much, as to render the cement impenetrable to any more water: it seems also that an acid of the vitriolic kind, which is contained in terras as well as in boles, contributes to the speedy setting of this cement, by reducing a part of the lime to the condition of gypsum.

SECTION XVI.

Experiments shewing the Effects of Plaster Powder, Alum, Vitriolic Acid, of some metallic and earthy Salts, and of Alkalies, in Mortar. Practical Inferences.

IN my best mixtures of coarse and fine Thames sand with one-seventh and with larger quantities of lime, I tried the gypseous powder of which plaster of Paris is made; and found it to be injurious in proportion to the quantity of it. The particular effects of gypsum in mortar, were such as might be expected in consequence of our knowledge of the saline nature of it; gypsum being a compound of calcareous earth and vitriolic acid, which is soluble in water, not so freely as neutral salts, but rather like lime: it disposed the mortar to set faster than it could be applied in stuccoing; it contributed very little to the plasticity of it; and the cement was the more apt to soften in wet weather and to perish in time, as the quantity of plaster powder

der in it was greater. The greatest quantity tried was only one-seventh of that of the sand.

ALUM was found very injurious. The acid of alum formed selenite or gypsum with a part of the lime, and thus operated like gypsum or plaister powder; whilst the earth of the alum induced the imperfections which attend the use of clay. The greatest quantity of alum used was one part in ten of the best mixture of sand and lime; and this specimen mouldered, in nine or ten months, like marle.

VITRIOLIC acid, which formed selenite or gypsum with a part of the lime, produced the effects of a quadruple quantity of plaister powder.

VITRIOLS of lead and of tin, being decomposed by the lime, operated like smaller quantities of vitriolic acid: martial vitriol or copperas had the same effect, and induced an olive colour, which was soon turned to that of rust.

VITRIOL

VITRIOL of zinc or white vitriol, and Epsom salt, did not dispose the mortar to set hastily, nor injure it in any particular discoverable during the application and drying of it; for these vitriols are not easily decomposed by lime: but afterwards I perceived that they impeded the induration of the stucco, and disposed it to suffer by the weather, the more as the quantity of either of them came near to be one-tenth of the quantity of sand.

VITRIOLATED tartar, Glaubers salt, and the salts which are found in most of our waters, such as sea salt, nitre, marine calcareous salt, calcareous nitre, and that composed of magnesia and marine acid, were found like Epsom salt to injure the best mortar: so were caustic mineral alkali; caustic vegetable alkali; and liquor filicum. Caustic volatile alkali, which soon exhales by reason of its volatility, had no sensible effect. I did not try argol or mild alkalies, because they reduce the lime to whiting; neither did I use any acid which forms a very soluble salt with lime, for obvious reasons.

KNOWING that the lime which has been employed by soap-boilers to render their barrilla and pot-ash caustic, contains, even after the repeated elixations, a little alkali and vitriolated tartar blended with the calcareous earth; and that the greater part of this last is restored to the condition of chalk, by the acidulous gas imbibed from the alkaline salts; I had, in consequence of the foregoing experiments, sufficient reason to presume that this refuse matter of the soap-boilers cannot answer the purposes of lime, or improve our mortar. But as a pretence to the contrary is made by some artists, and appears in the Builder's Dictionary, and as the cheapness of this article is a temptation towards their extending the use of it, I resolved to decide this question by direct experiment.

AFTER trying, in my usual method, specimens of mortar made with the refuse of soap-lees and my best sand, in different proportions; and others made with this sand, lime, and the refuse matter, in various proportions; I found the first destitute of the most useful properties of good mortar; and the others were defective, in proportion to the

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quantity

quantity of the refuse matter relatively to that of the lime. Whether this matter improves mortar made with gravel and the common chalk-lime, or encreases the defects of it, is a question not worth our notice.

THE experiments lately related shew that lime is the more unfit for building and external incrustations, as it contains more gypsum; and I must now remark that most kinds of lime-stone used in England contain considerable quantities of this matter which is not much corrected in the burning: But as I have, in the second section, enabled my readers to discover this imperfection, I hope I shall be excused from the invidious office of depreciating or recommending any particular lime-stone or manufactory of lime.

THE cautions which our last mentioned experiments suggest with regard to the use of water, are especially necessary in this country, where most of the wells and springs abound with one or more of the above-mentioned salts; and it is not to be presumed that the quantity of these contained in water which is used for culinary purposes, cannot
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be injurious in mortar ; for I know that felenite, Epsom salt, the very deliquescent salts compound of magnesia and marine acid and of calcareous earth and the same acid, may, together with a little sea-salt, be natively dissolved in water, to the quantity of half an ounce in a gallon, without affecting the taste of it sensibly. When we consider the quantity of water necessary in slaking the lime making the mortar and wetting the thirty bricks, and the smallness of those portions of salts, whose injurious effects were discoverable in the course of one year, or in a shorter time, we find sufficient grounds for concluding that such saline waters will be found hurtful in mortar, before many years elapse, particularly where it is exposed to moisture. Indeed this has been already experienced of sea-salt, even in the small quantity of it introduced in mortar, when the sand is taken from the sea shore. The easiest method of discovering the quantity of saline matter in water, consists in evaporating it slowly to dryness and weighing the residue : water which deposits calcareous earth as soon as it is heated, ought to be cleared by subsidence or filtering, before the evaporation is completed.

WHEN a choice can be made, rain water is to be preferred ; river water holds the next place, land water the next, spring water the last ; and waters noted medicinally or otherwise for their saline contents, ought not to be used at all in mortar ; for the salts contained in them are those which were tried, the vitriolated tartar excepted.

SECTION XVII.

Experiments shewing the Effects of skimmed Milk, Serum of Ox-Blood, Decoction of Lint seed, Mucilage of Lintseed, Olive Oil, Lintseed Oil, and Resin, in Mortar ; and the Effect of painting calcareous Incrustations.

AT the same time and in the same mixtures of the best sand and lime, I tried skimmed milk, serum of ox-blood, decoction of lintseed strained, and thick mucilage of lintseed, in the place of lime water.

THE mortar made with any of these was fatter as the liquor was more glutinous, but was as liable to crack as mortar made with water. In the course of a year it appeared that each of these liquors encourages a vegetation to take place on the surface, which gives it an ugly appearance, and tends to ruin it ; and that they all prevent the cement from acquiring the experienced hardness of

our best compositions, or indeed from having any competition with them in this particular.

THE notion therefore which is entertained by the builders, concerning the use of skimmed milk and blood, is erroneous, unless it be confined to the viler kinds of mortar, which may perhaps be improved by them; because a composition of sand whiting and mucilage, grows harder than that of whiting and sand kneaded with water.

It seems to me that glutinous liquors and good lime act reciprocally on each other, in the time of mixing them, to the destruction of their respective characters, and particularly to the conversion of a part of the quick lime into whiting; and that if any kind of mortar is improved by them, it is then especially, when the workman takes advantage of the fatness induced by them, and using less than his customary quantity of lime, secures his work from cracking.

OLIVE oil mixed with good mortar, or substituted in the place of a part of the lime water,

ter, rendered the cement defective, as the quantity of oil was greater. The greatest quantity used was half that of the lime.

LINTSEED oil used in the same manner, makes the mortar fatter, retards the drying of it, and prevents it from acquiring in any time, so great a degree of hardness as it otherwise would have. It was the more hurtful as the quantity of it was nearer to that of half the lime : in much smaller quantities it was less injurious than olive oil. From my observations on this subject, and on the compositions called oil cements, I have reason to conclude, that no oil ought to be used in a cement which consists chiefly of sand lime and water ; nor any water or watery liquor, in a cementious mixture, which is moistened and kneaded with oil chiefly.

As lintseed oil whiting and sand make a cement which hardens to a great degree, in dry situations, and abides the weather a long time before the hardened oil relents, it is not improbable that lintseed oil may meliorate mortar made with bad lime. But good lime and lintseed oil seem to injure each other, in forming

ing a kind of saponaceous compound with the lime water of the mortar,

FROM the experienced effects of saline, gelatinous, and oleaginous matter, I infer that cow-dung, which I have not tried, would impair good mortar. It makes the common mortar fatter, and in that respect more convenient for pargeting the interior surface of chimney flues: it seems likewise to prevent the parget made with bad lime, from drying so quickly and from cracking so much as it otherwise would do; the fibrous part of the dung being capable of contributing largely to this latter effect. On these grounds it may be useful in bad mortar thus applied, whether it increases the hardness of it or not; altho' it is likely to impair good mortar.

POWDER of resin intimately blended with mortar by grinding it with a part of the lime and lime water, was hurtful according to the quantity of it; the greatest quantity tried being one-fourth of that of the lime.

BEFORE I knew the event of these experiments I made an incrustation on a wall front-
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ing the south, but shaded from the sun after mid-day, with a cement composed of seven parts of my mixed sand, one of the best stone lime, and the necessary quantity of lime water. As soon as the incrustation was dry, which happened in four days, I painted one-third of it with lintseed oil prepared for painters use, another third with white lead paint, and the remainder was separated from these by a channel cut between them.

AFTER fourteen months the last-mentioned portion was very hard near the surface, and the induration extended deeply in the mass of it, though not in so great a degree of perfection as that of the surface: The painted portions were also very hard at the surface, but internally much weaker than the other.

FROM my observations of these specimens, and of divers incrustations in this city, which being made of bad calcareous cement, have been painted and sanded, in order to fill the cracks and fence them from the weather; I have had sufficient reason to conclude, that an incrustation, made as good as it may be with lime and sand and lime water, is not bettered by painting

ing it as soon as it dries; that this covering retards the induration of it, by cutting off its communication with the air; that it therefore renders it liable to be irreparably injured in wet weather, wherever the water can get behind the paint; and that if paint or oil ought ever to be applied on such stucco, it ought not to be used in less than a year after the incrustation is made: I likewise found that the painting and sanding of the common defective incrustations, contributes very little to their duration, although it hardens them at the surface; for it does not effectually prevent them from cracking; and it avails very little to paint the cracked stucco again; because cracked stucco is always hollow, as the workmen term it; that is, it parts from the wall in the parts contiguous to the cracks, sounds hollow on being struck with the knuckle, and falls off in a few years, if it be so thick and large in extent as to break the adhering portions by its weight.

SECTION XVIII.

Experiments shewing the Effect of Sulphur, introduced by different Methods, in Mortar.

IN my first trials of sulphur, it seemed to be useful; and this led me to try it in so many different ways, and in so many mixtures of lime and sands, and of these with flint powder and divers other substances, as would render the recital of all my observations on the effects of it inconsistent with the plan of this essay: I must therefore content myself with communicating those which I think most useful, in such terms as may give some intimation of the manner in which the experiments were made.

WHEN the livigated powder of sulphur was mixed with mortar already made of good materials and did not exceed one-thirty-second part of the mass, it seemed to improve it, in the first and second month, and sometimes during a longer time of comparison with
mortar

mortar made of all the same materials, except sulphur, in similar proportions : But in ten or twelve months the sulphur was found injurious, and the more so, as it exceeded the foregoing proportion. The most hurtful effect of it was, its disposing the mortar to relent in long continued rains, and grow quite friable after a few alternations of freezing and thawing. It had the same effect in mortar containing several of the ingredients already named and of those hereafter to be mentioned.

WHEN the sulphur was mixed with fresh powdered lime, and these were ground briskly with lime water, a calcareous liver of sulphur was formed, proportionate to the quantity of sulphur used ; and the mortar made with this mixture and sand, or with this and sand and other ingredients, was worse than mortar containing an equal quantity of the sulphur mixed in it in the former method.

THE transparent liquor called liquid calcareous liver of sulphur, which consists of sulphur dissolved in water by the intervention of lime, being used instead of water in making mortar with sand and lime in any proportions, was found more injurious

jurious than three times this quantity of undissolved sulphur was, in the first-mentioned method of using it: and this liquor had the like effect in mixtures of mortar with divers other ingredients. Whence I infer that sulphureous mineral waters ought not to be used in mortar.

If the plan of these experiments had not comprehended the noxious as well as the useful ingredients, and I had not resolved to distrust every theory, I might have prognosticated the event of these mixtures, in consequence of my certain knowledge of the operation of sulphur lime and air on each other.

WHEN sulphur and lime are moistened with water, and exposed to air, the acid of sulphur being attracted by the lime, whilst the phlogiston of the sulphur is attracted by the air, a decomposition of the sulphur takes place, and new compounds are formed. The acid and lime gradually form selenite or gypsum, whilst the air combined with the phlogiston is wasted away. Therefore lime, by so much of it as is thus expended in forming
gypsum,

gypsum, is not only unable to act as a durable cement of the grains of sand, but is capable, according to the experiments of the sixteenth section, of counteracting the cementing powers of the residuary part of it, when the mass of sulphurated cement is exposed to the weather.

THE pleasing warm colour which sulphur induces in calcareous stucco, whilst it is fresh, and the promising appearances of such an incrustation in the first year, have, if I am rightly informed, already misled an artist to apply it freely at his own risque. I wish these observations may serve to undeceive him.

ABOUT this time, the imitation of coloured stones, by incrustations, became an object of my attention; and some of the subsequent experiments were made with a view to it, as well as to the purposes already expressed.

S E C T I O N XIX.

Experiments shewing the Effects of Crude Antimony, Regulus of Antimony, Lead Matt, Potter's Ore, White Lead, Arsenic, Orpiment, Martial Pyrites and Slaked Mundic, in Mortar.

CRUDE antimony reduced to an impalpable powder and then ground with the lime and lime water, operated in mortar as sulphur does when it is used in the same manner and in the quantity which the crude antimony contains. The antimonial powder moreover induced a disagreeable blueish colour, which in a little time became brown and afterwards yellowish.

WHEN the powder of antimony was mixed in the mortar after it was made it was less injurious.

REGULUS of antimony tried in the same way, seemed to have no other effect than
that

that which is produced by the admixture of flint powder or other fine powders of hard bodies.

POWDERED lead matt and potter's ore of lead acted like crude antimony, but more slowly and weakly in equal quantities of them.

WHITE lead was found exceedingly injurious, which I expected; for I had long before discovered and shewn in my public Courses of Chymistry, that a great part of white lead is acidulous gas, into which vinegar is easily convertible in the process for making white lead and in many others; and I foresaw that the lime, attracting this matter, would be reduced to the condition of whiting in the time of making the mixture, and that the mortar would consequently be defective. The white lead, as fast as its acidulous gas is drawn from it by the lime, becomes yellow like massicot. As white lead improves the oil cements, these experiments shew that there is no true analogy between the calcareous water cements and those which are called oil cements.

ARSENIC

ARSENIC operated in mortar like the neutral salts ; and orpiment produced the injurious effects experienced of sulphur and of arsenic ; which effects were greatest when the orpiment was ground with the unslaked lime and lime water. Orpiment imparted a dark brown colour at first, which soon became yellow and afterwards disappeared.

THE martial pyrites called mundic, heated to redness, and then flaked by moistening it with water whilst it was hot, operated like crude antimony, with this difference only, that a greater quantity of it was required to produce the same effect ; for this reason, as I conceive it, that the quantity of sulphur in martial pyrites is less than in crude antimony, and being held in it by a more forcible attraction, is prevented from acting so freely on the lime of the mortar. The colour induced by the flaked mundic was at first blueish and afterwards turned to that of iron rust.

THE mundic, which was that of Wiel-Virgin in Cornwall, used in its native state, in mortar, kept me in suspense upwards of twelve months. It was tried not only on

L tiles,

tiles, but in large incrustations on walls, because it promised great advantages at first. When the quantity of it did not exceed one twenty-fourth of that of the mortar, it manifestly increased the induration of the cement during the first nine months; but after fourteen or fifteen months it disposed the incrustation to relent, the more as it was oftener wetted or as the place was damp, and from being exceedingly hard, to become penetrable to a pointed instrument pushed only with the hand, and as brittle as chalkstone. The colour and changes of colour of the mortar containing native mundic, are similar to those produced by the flaked mundic, and are not at all pleasing to the eye. The effects of much smaller quantities of this matter in mortar do not yet appear so clearly; but there is no reason to presume that they will be of the same kind, though in a smaller degree.

THESE and the preceding experiments indicate that all bodies soluble in water, not excepting arsenic, and all those which are capable of efflorescing, or of being decomposed by air and moisture, are hurtful in mortar; and they teach us to avoid those kinds of gravel
which

which are impregnated with pyritous matter, whether it be arsenical, metallic, aluminous, or calcareous. The effects of regulus of antimony, and the speedy decay of the cheaper metals, however perfectly they are desulphurated, give strong grounds for presuming that calcareous cements, which are to be exposed fully to the weather, are more likely to be injured than improved by metallic matter introduced in any form.

SECTION XX.

Experiments shewing the Effects of Iron Scales, washed Colcothar, native Red Ochres, Yellow Ochres, Umber, Powder of coloured Fluor, coloured Mica, Smalt, and other coloured Bodies, in Mortar. Advices concerning coloured Incrustations, Inside-Stucco, and damp Walls.

IRON scales from a smith's forge, which consist of iron semi-calcined, and are thought by many artists to improve mortar, were tried eighteen months ago, by grinding them to a fine powder, and mixing this in mortar, to half the quantity of the lime, and in smaller proportions.

THE larger quantities, in the course of twelve or fourteen months, appeared to be hurtful; and by these I judge of the smallest, which do not yet appear to produce any remarkable effect in incrustations made in dry situations, except the rusty colour which they induce. But in those which reached
near

near the ground, and in others made on tiles which were laid flat on the ground in a shaded damp corner, in both of which instances the incrustations were always moist, the iron powder seemed to render the cement a little harder than it could otherwise become in the same time in such circumstances, and it certainly made it closer in the grain.

By these experiments I am inclined to think that iron powder, which, during its conversion to rust, imbibes a great deal of acidulous gas and air, and swells considerably, may be used with success, where the proper induration of good mortar is prevented by continual moisture, and the chief purpose of the cement is, to exclude water perfectly, by the closeness of its texture, to which the swelling of the iron contributes not a little. If it is capable of producing any desirable effects in cements otherwise circumstanced, these are to be expected only when the quantity of it does not exceed one-eighth of that of the lime, or one-fiftieth of that of the mass of mortar.

WASHED colcothar of iron, native red ochres, yellow ochres, and umber, had the effects of smaller quantities of terras, or of equal quantities of flint-powder.

COLOURED fluor and micaceous stones, coloured marble, smalt, and divers other coloured substances, which are insoluble in water, reduced to fine powder, induced their respective tints in the incrustations, but acted like flint powder.

FROM the experienced effects of coloured calces of iron, and of divers sulphurated and perishable metallic powders, I learned that these ought not to be used in external incrustations; since they render them more defective as they colour them deeply; and I turned my thoughts to the discovery of some other expedient for inducing permanent colour without injuring the cement.

I SOON found that this may be done, with regard to the lighter and pleasanter tints, by the use of coloured sands, or the coarse gritted powder of hard and durable coloured bodies. Lynn sand affords a white cement
which

which is the better, as more of the finest part is sifted out of the sand. Thames sand makes a grey cement not unlike Portland stone, and this colour is agreeably varied by the use of grey bone-ash, of which we shall presently treat.

A RICH yellow tint is obtained by using the golden yellow sands, of which kind there is one near Croydon in Surrey ; and a small quantity of this sand mixed with Lynn sand, gives a warm white, and with Thames sand, an exact resemblance of the Bath stone. These are the most eligible tints for the fronts of houses.

UNTIL I had tried the glistening scaly talcs, I imagined they would serve to impart all other tints, as they may be had of any colour, and are as durable as they are pleasing to the eye : but they were found to weaken the adhesion of the cement to the wall, and to make it so rough and short, that it was almost impossible to form a smooth compact incrustation with it, unless the lime were used in excessive quantity ; and in the course of eight or nine months it ap-

peared that the cements, in which they were mixed in the quantity necessary to produce strong tints, were rendered spongy, and greatly weakened by them.

SCALY glistening mica, strewed equably on an incrustation previously wetted with a thin mixture of lime water and lime, and gently compressed to lay the scales flat, imparts its colour with the fullest effect. In this way coloured mica may be used, where it is cheap, on external incrustations, if the perspective appearance of a building can be improved by different colours of any members of it: and this kind of colouring greatly excels painting, in the fickle weather of our climate, because it lasts unfaded, as long as the micaceous crust.

To tinge a cement sufficiently for prospect or contrast, of any colour which is not found in sand, so that the incrustation shall not be impaired, and that the colour shall be as durable as the cement; I found nothing more adviseable than to use, in the place of the sand, or of a part of it, coloured glasses or coloured stones of the hardest kind, beaten to
coarse

coarse powder, the finer parts of which are to be washed away, not merely because they are injurious to the cement, but because I have observed that they contribute very little to the intended colour.

THE drying, induration, and texture of incrustations made on brick walls and other irregular surfaces, are always so far unequal as to exhibit visible traces, which deform the work and cannot be effectually obliterated by any known method so convenient as that of covering the first coarse incrustation, after it has dried, with another coat which may be made finer and smoother. Thus the expence of fine grained smooth or coloured stucco is rendered moderate; because the finer, or the colouring materials, may be reserved for the exterior coat, which will last for ages, if the cement be good; as we shall shew, when we come to consider the experienced duration of the best calcareous cements,

As the mouldings and paintings which are expended on the soft stucco now used, and which contribute so much to the magnificence of our apartments, can be equalled, in
their

their ornamental effects, by the double incrustations which I have described, and greatly exceeded by these last in the hardness and duration of them, I do not doubt that plaisterers will adopt this improved method, when they find that it is consistent with their own interest, as well as with that of their employers.

I AM not sufficiently acquainted with their business to form a just estimate of this subject; but I will submit to their consideration a few observations which would influence me very much in the choice of stucco for a house of mine.

THE compositions heretofore used for stuccoing within doors, are incapable of hardening considerably, and when they are laid on the naked walls, soon become tarnished, unsightly, and inconvenient, by the damps which the workmen call sweating, and which are, in my opinion, of two kinds; one I will call damp by transpiration, the other damp by condensation. The damp by transpiration occurs, when the principal walls are stuccoed before they have dried, or when
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the materials of them are so spongy as to imbibe the rain, and the circulation of air within the house is not sufficient to waft away the moisture which transudes from the wet wall into the stucco; and especially when the exhalation of this moisture from the stucco, is impeded by the closeness of its texture; for all such bodies retain moisture the more forcibly, as their pores are smaller, and as the air meets more difficulty in pervading them. I see no reason to doubt that this inconvenience would be obviated by making the incrustation of a texture similar to that of the materials on which it is laid; and that the cement made with about seven parts of sand, one of lime, and the lime water, and improved, as we shall teach hereafter, by the admixture of bone-ash, would continue dry in such circumstances, because moisture quickly exhales from it, by reason of its texture.

THE damp which seizes incrustations, when the walls are badly constructed, when the joints of the facing bricks become hollow by the decay of the mortar, or when the co-

pings

pings or gutters are defective, do not fall under our consideration.

THE damp by condensation appears most on the finest and closest incrustations, however perfect and old the walls may be. To find the proximate cause of it, we need only to advert to that which gathers on glass windows, whilst the wainscoat and other spongy bodies, which serve to inclose the same rooms, remain dry; or to the moisture which gathers on walls faced with the closer kinds of ornamental marble, in sumptuous buildings, at the same time when the walls and incrustations, which are contiguous to them, and are of a coarse texture, are quite dry. In these and other instances we may perceive, that the damp is owing to the closeness of these bodies, and that a stucco pervious in a certain degree to air and moisture, will be free from it, as well as from the other lately mentioned.

THE plaisterers, finding their stucco, which is as fine and close as they can make it, liable to contract these damps, especially on the principal walls of houses, case them with lath-work, on which the incrustation is laid distant from the wall. In this way
they

they obviate the appearance of damp ; but they at the same time contract the rooms, and narrow passages and staircases sensibly, at a great expence. This is enhanced by the repeated plaistering necessary to fill the slender cracks which disfigure their incrustation during the drying, and by the oiling or painting which is finally required to hide this defect compleatly, if not to give colour. Thus the work becomes costly, although the plaisterers profit is moderate.

ON these considerations I am inclined to the opinion that it will be found as advantageous to the plaisterer, as to his employer, to prefer our cement before any other, for internal incrustations ; especially when no other colour is required, besides those which may be imparted by coloured sand, or materials which do not greatly exceed it in price. I would not interfere with the workman, in forming an exact comparative estimate of the expences, if I could do it ; but I will venture to affirm that an incrustation made as I have described, or in the improved method hereafter to be shewn, will be found ultimately cheaper than any other yet discovered, for
the

the following reasons. It will be more durable by reason of its greater hardness; it will retain its colour longer unfaded, because the colouring materials do not tarnish or perish like paint; it will preserve the sharpness of the mouldings and the elegance of its appearance longer, because it will not require the frequent painting which soon blunts the figures and mouldings of ordinary stucco; it may be finished with less labour, because it is not apt to crack in these circumstances, and does not need many coats and repeated plaistering; and as it is not likely to contract damp, it will save all the expences and inconveniences of lath-work, whether it be laid on partitions or on principal walls, provided the cement applied on the former be not made of the finest materials.

If a polished and white surface of our stucco should be required, it ought to consist of two layers: the first of which is to be coarse and capable of hardening to the highest degree; the second is to consist of flint powder lime and lime water, and is to laid on very thin, and finely smoothed. To give a rich colour together with a smooth surface, to our
best

best incrustation, we must use, in the place of flint powder, for the finishing coat, the coloured powder of sands, or stones, or glasses; and introduce as much of the colouring ingredients used in painting, as will be sufficient to give the required appearance, avoiding those which are spoiled by lime.

To my eye, the warm white, or coloured stucco which is not quite smooth, is the pleasantest: but those who prefer the smoothest, may have it made at a moderate expence, in this last-mentioned method, in which the useful and solid part of it, contributes to the support and duration of the weaker ornamental coat, which thus circumstanced is likely to preserve its beauty for a very long time, although it might, in the weather, be impaired in three or four years.

SECTION XXI.

Experiments shewing the Effects of common Wood-ashes, calcined or purer Wood-ashes, elixated Ashes, Charcoal Powder, Sea Coal-ashes, and powdered Coak, in Mortar; and Observations on their integrant Parts, and the Differences between them and the Powders of other Bodies.

THE ashes of wood and sea-coal are frequently mixed with mortar, or used in the place of sand, in laying tiled floors, and even in external incrustations. Some workmen say they are used in the former case to save sand; others that they serve to resist moisture; and those who seem to be the best informed affirm, that they hasten the drying and induration, and prevent the cracking of mortar which is laid very thick in order to fill the depressions of walls which are to be stuccoed; and that they are used in finer incrustations with the sole view of preventing cracks.

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THE ashes of the same kind of wood differ, according to the circumstances in which they are formed, even upon the same hearth, not only in colour, but in other particulars known to chemists, which I shall attend to presently. As the separation of these different sorts of ashes is not practicable at a moderate expence, and never is attempted by the workmen, I contented myself, at first, with procuring the ashes of cleft pollards burned on a hearth, and with sifting the whole quantity of them, to free the finer part from the fragments and coarse powder of charred wood which formed a great part of the bulk of them. The sifted ashes were grey inclining to brown, strongly alkaline to the taste, and viewed through a convex lens, were found to contain a considerable quantity of fine charcoal-powder, which I estimated at one sixth or more of their bulk.

To learn the effect of the purer ashes, or of the more dephlogisticated earthy and saline parts separated from the charcoal, I took about a gallon of the sifted ashes, and burned them on a test in a reverberatory furnace, with a heat not exceeding that of a culinary

M fire

fire, taking care to accelerate the combustion of the charcoal powder contained in them and render it equable thro' the whole heap, by stirring it, and presenting fresh surfaces to the air, until the whole was rendered incombustible. After this process, the powder, which I shall call calcined wood ashes, was rather brown than grey, and retained its saline taste.

ON trying the sifted wood ashes in my best mortar, and in other mixtures of sand and lime, I found that they gave the cement a spongy texture, and enabled it to dry without cracking, when the lime was not used in excessive quantity; but that they prevented it from acquiring the hardness of mortar made of lime and sand only: so that the advantages which they promised to afford in certain circumstances, appeared to be counterbalanced by the permanent weakness induced by them; which latter effect was the greater as the quantity of the ashes came nearer to equal that of the lime.

THE calcined wood ashes likewise prevented the mortar from cracking, without making it so spongy: but they manifestly impeded

peded the induration of it, and disposed it to be injured by rain, in the same manner as small quantities of alkali were found to do.

ON a strict comparison, the calcined wood ashes, which we may consider as ashes freed from charcoal powder, appeared to be much more injurious than the uncalcined. This I imputed to the greater quantity of alkali in the former, which is hurtful in a double capacity; first as a saline body; and secondly as a compound which yields its acidulous gas to lime, in the instant of mixture, and consequently impairs the cement.

MORTAR made with bad lime in the usual proportions may nevertheless be improved by sifted wood ashes; for the coal and earthy part of these, if they were only equivalent to so much sand, render it less liable to crack; and the bad effects of the alkali may be greatly overbalanced by this advantage, in an incrustation which is required to be rather uniform and secure from cracking, than hard and durable in the highest degree.

I MUST not omit this opportunity of observing that calcined wood ashes, and even the sifted fresh wood ashes, improve plaister of Paris in hardness, to a very great degree, if it be kept in a dry place. The solution of this phænomenon is not difficult.

ANY person who intends to repeat my experiments on calcined wood-ashes, ought to take care that they be not calcined with a stronger heat than I described; for if he exceeds this, the ashes, after the signs of their combustion have ceased, will smother strongly, a part of the saline matter being sublimed in the mean time; and the remaining earthy and saline portion will form a light grey or brown semivitrified gritty powder, or will concrete into lumps. This matter will then be found insipid and equivalent to sand, in mortar, as I have experienced; for it differs as much from wood ashes, as the powder of potters-stone-ware differs from the raw clay.

WHILST I was employed in these experiments, the following thoughts occurred to me. The ashes used by the workmen, being passed through a coarse sieve, may consist
for

for the greater part, of charcoal, which afterwards is beaten finer in making the mortar : The ashes used by builders whose durable works authorized this practice, might have been the refuse of manufactories of pot-ash, in which the saline matter is always carefully extracted from them ; and charcoal powder or elixated ashes may greatly improve mortar, altho' ashes finely sifted and replete with salts should impair it. I therefore boiled my calcined wood-ashes in water, and repeated this operation twice in fresh water ; knowing that one elixation does not free the ashes perfectly from the saline matter : I then dried the insipid ashes thoroughly, and used them in this state, under the name of elixated wood-ashes. At the same time I provided charcoal powder sifted thro' the same sieve which I used for the wood-ashes.

AFTER a great number of experiments made in the usual manner with the elixated ashes, I found that they rendered the mortar spongy, disposed it to dry and harden quickly, and prevented it from cracking, more effectually than the like additional quantity of sand would do it. They did not ap-

pear to induce the defects attending saline bodies in mortar ; they only made it weaker, as the quantity of the elixated ashes was greater relatively to that of the sand or lime. This weakness, however, was not such as the unwashed ashes or saline bodies produce, but rather of the kind which I pointed out in those parts of the foregoing sections, wherein I endeavoured to shew, that cementitious masses resist edged instruments or any force tending to break them, the more weakly, as they contain more of the softer and brittler calcareous matter, or as softer grains are substituted for a part of the sand.

IN every comparison of the specimens containing unwashed wood-ashes, with those in which the elixated ashes were mixed in the same proportions, it clearly appeared that the latter are to be preferred ; and that neither of them ought ever to exceed half the quantity of lime, in good mortar.

As flint powder and other earthy powders were found to dispose mortar to crack, I could not conceive how the elixated wood-ashes operated so effectually in preventing
this

this defect, until I examined them attentively, and found them to differ from the other powders in two particulars. Elixated wood-ashes contain very little powder of the finer kind; they feel gritty between the fingers, and appear to consist of ragged spongy small grains compressible to a considerable degree in the heap. How a powder thus conditioned prevents the cracking of mortar or otherwise improves it, I shall attempt to explain, after stating other facts upon which my notions of this subject are founded.

CHARCOAL powder had the same effects as elixated wood-ashes, with these differences only, that the cements containing the larger quantities of charcoal powder could be more easily cut, and were of a bluer colour, than those containing the like quantities of elixated wood ashes. The powder which I used was sifted like the ashes; and, viewed through a microscope, answered to the description lately given of elixated ashes,

THE skreened ashes of Newcastle coal consist chiefly of charred coal or coak, and as they contain very little saline matter, are insipid.

When I reduced them to powder, and passed them thro' the sieve, they answered to the description given of elixated wood ashes, and produced nearly the same effects in mortar. They did not weaken it so much as charcoal powder had done ; which I impute to the greater hardness of the small grains of coak.

IN all these comparisons, it is to be understood that I made them at the same periods of the induration of the several specimens.

FROM these experiments I conclude that, where a choice can be made, these powders are eligible in this order ; elixated wood ashes freed from the finest powder in washing, first ; powdered coak or sea coal cinders, next ; charcoal powder next ; rough wood ashes powdered, last : But well burned fine unwashed wood-ashes ought not to be used at all in external cementious work or incrustation,

THE last of these gives a disagreeable grey or dusky colour to the cement ; and the others, a blueish or slate colour, still more offensive to the eye ; for which reason they
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are unfit for any work that is not hid from the view.

As my reader may not fully understand what I briefly mentioned concerning the sensible difference between these last examined powders, and others noticed in the preceding sections, I will thus exemplify my notions. Wood consists of watery and volatile parts which are expelled by heat, and of fixed parts which constitute the charcoal : and charred wood, which greedily imbibes air or water in great quantity, may be considered as an assemblage of capillary tubes of divers figures and sizes. So we may likewise consider the fragments of charcoal, and each visible grain of its powder. But as the most brittle bodies are flexible when they are made sufficiently thin, the charcoal powder is an assemblage of small flexible or compressible tubulated bodies,

As the charcoal which is the more fixed and solid basis of wood, is spongy after the juices are expelled in charring ; so the ashes of charred wood are, after the elixation, an assemblage of spongy or tubulated grains out
of

of which the phlogistic matter has escaped during the combustion : and the texture of these grains differs from that of the grains of fine sand or of flint powder, in the same manner, if not in the same degree, as the texture of sponge differs from that of a flint. And we may conceive the unwashed wood ashes, as a heap of small spongy bodies clogged with alkaline salt.

UPON the same grounds, the relation of coak or sea-coal-cinders to the raw coal, is analogous to that which charcoal bears to wood, or spongy pumice stone to porphyry ; and transferring these observations to bones, and considering the smaller vessels and finer texture of them than of wood, we shall find the powder of charred bones to consist of tubulated or spongy bodies like those of charcoal powder, but pervious by slenderer and harder tubes ; and bone-ash, which is the gritty powder of well burnt bones, to have the same relation to the charred bones, which elixated wood-ashes have to charcoal powder.

THUS I have thought of these substances, after having observed what happens to them
in

in the preparation ; examined them by a microscope ; experienced their effects to be so different from those of finest sand, or powdered stones, in mortar ; and finally discovered, by repeated experiments, the detail of which is not now necessary, that semivitrification, which destroys the spongy texture, and levigation, which breaks these spongy grains down to the particles of which they are constructed, render charcoal powder, wood-ashes, powdered sea-coal-cinders, and others of the like kind, incapable of acting in the manner described, in calcareous cements.

ALL these things being considered, I impute the effects of these ashes, or powders, to the tubulated structure and compressibility of the integrant parts of them ; and in the next section I shall offer all that I have attempted further, theoretically or practically, relative to this subject.

SECTION

SECTION XXII.

Experiments shewing the Effects of white and grey Bone-ashes, and the Powder of Charred Bones; and Theory of the Agency of these in the best calcareous Cements.

LONG before I had tried all the powders heretofore mentioned, I used bone-ash in many experiments, and saw the effects of it in mortar. For the sake of brevity and perspicuity I reserved the relation of them for this section: and in order to shew more clearly the analogy in texture, between bone-ashes and the powders lately mentioned, and to suggest the means of procuring them in any part of this country, I will premise a sketch of the most profitable processes by which they are prepared, at a moderate price not much exceeding that of good stone-lime.

THE

THE bones collected in great cities, are broken to small fragments in a mill, and boiled in water, in order to extricate and save the oil of them. They are then put into a large iron still, through an aperture which is stopped up closely after the charge is made. The still, which opens into an apparatus of refrigeratory vessels, is heated gradually to redness, until all the volatile alkali, commonly called spirit and salt of hartshorn, is expelled from them, together with empyreumatic oil, water, and certain elastic invisible fluids : The alkali, being the only valuable article amongst these, is retained and condensed in the refrigeratory tubes and vessels with all possible care, whilst the elastic fluids, lest they should burst the vessels, are suffered to escape in places distant from the fire or the flame of candles, because they are combustible, and if they catch fire whilst air remains in the condensing vessels, explode like gunpowder.

THE bones thus heated without being exposed to the air, are charred to blackness, but still remain combustible. When they are required in this state, the iron still is
kept

kept closed until they cool, and then the blackest of them are ground to fine powder, which is used as a substitute for ivory black, which is prepared in the same way from ivory. The coarser powder of these, is what I understand by powder of charred bones. But when this is not the manufacturer's design, the door of the iron still is opened whilst it is hot, and the charred bones, which flame and burn when they meet the air, are thrown into a kind of kiln, at the bottom of which the air can freely enter, and maintain the combustion, until the bones are burned to whiteness, for the greater part. The white fragments are picked, and rather bruised, than ground, to a gritty powder, by a millstone which rolls on them vertically over an inclined circular plane. This powder passed thro' a sieve is called bone-ashes, which are much used in metallurgy, and fitter for our purposes in incrustations, than the powder of burned bones ground as pigments are. The fragments which have not been thoroughly burned in the kiln, form a dark grey powder; and mixtures of the white and grey burned bones afford bone-ashes of the lighter grey colours.

THE whole quantity of bone-ashes, which is to be used in the same incrustation, ought to be well mixed ; for it is impossible to sort the well burned or the grey bones so accurately as to secure an unity of colour in the parcels of powder which are successively prepared, and a very small variation of colour will be seen in the incrustation.

MR. JOHN OLIVER of Hoxton, who is a very liberal and ingenious artist, prepares bone-ashes, judiciously adapted to the purposes which I am now to mention, at a very low price, as well as the coarser kind which is used in making cupels and tests by the refiners. I shall distinguish the former by the name of sorted bone-ashes ; because they are freed from the finest and the coarsest parts of the latter.

As I knew that bone-ashes consist chiefly of calcareous earth, and may be reduced to lime, by dissolving them in acids, precipitating the solution by alkalies, washing the precipitate perfectly and then burning it, I tried them with sand in different ways, in order to learn how far they resemble lime in their cementing

menting properties ; and found that the sorted bone-ashes had very little effect ; but that compositions made with the levigated powder of these and sand and water, were nearly equal in hardness to those made with whiting and sand kneaded with water in the same proportions, and were not so liable to crack. Hence I inferred that bone-ashes, of which five-sixths are calcareous earth, could not improve mortar by any augmentation of the cementing powers of the lime, although they might be useful in other respects, and that they could not supply the defect of lime in quantity or quality.

IN the course of two years I made so many experiments with bone-ashes mixed in mortar composed of lime sand and lime water, in different proportions, and of these with divers other ingredients, that I may venture to say I attained a thorough knowledge of their effects, and need not hesitate to relate them in the style of precept.

THE sorted bone-ashes, mixed with mortar in any quantity not exceeding that of the lime, dispose the cement to set speedily without

out cracking; and effectually secure it from cracking, if it does not contain lime in superfluous quantity: They likewise give a texture which is the more spongy as the quantity of the bone-ashes is greater; and they accelerate the induration of it through the whole mass.

THE sorted bone-ashes encrease the plasticity of fresh mortar which is made with the smaller quantities of lime in order to secure the work from fissures; and thus they are useful in a triple view, in external incrustations; by facilitating the operation of plaistering, by preventing cracks, and by bringing the incrustation quickly to a state in which it is not easily injured by unexpected rain.

WHEN the sorted bone-ashes exceed the lime in quantity, they sensibly injure the cement, by rendering it weaker. How these ashes, which are not equivalent to sand in the hardness of their grains, nor to lime in their cementing powers, operate to weaken the cement, may easily be conceived, in con-

N sequence

sequence of the observations made in the ninth, twelfth and thirteenth sections.

WHEN the sorted bone-ashes are mixed in mortar in the quantity of one-fourth of the lime, they improve the plasticity, if the mortar be short, and they produce the desirable effects above mentioned in a sensible degree, without weakening the cement in the same proportion. As a smaller quantity of them seems to be useless, and a greater quantity than that of the lime injurious, the following rules are to be observed.

WHEN the artist is more solicitous to secure an incrustation from the effects of hot weather, to finish it quickly, to hide the traces of brick-work which are apt to appear thro' it, and to guard it against rain, than to make it hard and durable in the highest degree; he is to use as much of sorted bone-ashes as of lime: When the season, exposure, and other circumstances permit him to attend solely to the true excellence and duration of his work, he is to use, in our best calcareous cement, only one part of the sorted bone-ashes for every four parts of lime. By these
rules

rules he may chuse intermediate quantities adapted to his purposes.

THE coarser bone-ashes used in making cupels and tests, do not go so far, so the workmen express themselves, or do not operate so effectually, as the sorted ashes, in equal quantities of them by weight; and finer or levigated bone-ashes are rather injurious than useful in the coarser cements.

THE black powder of charred bones, and grey bone-ashes have nearly the same effects as sorted bone-ashes have, when the powder of them is sorted in the same manner; excepting what relates to colour.

THESE observations on bone-ashes were made before the expiration of 1777, on specimens of mortar laid on tiles, and small pieces of incrustation made on the walls of my house and on the fence-walls behind it: But they were not thoroughly confirmed until a comparison was made between large incrustations laid in trying aspects and containing bone-ashes, with those made close by them of my best mortar, in the year 1778;

when I discovered the difficulty expressed in the fourteenth section, of making extensive incrustations, in certain circumstances, so free from defects, as the smaller ones were which I had made at home.

In this last mentioned year I was favoured by Mr. James Wyatt of Queen-Ann-street Cavendish-square, the celebrated architect of the Pantheon, and by his brother Samuel Wyatt of Berwick-street, who is a very eminent builder, with the best opportunities of making these comparisons: for they ordered the plaisterers employed under them to apply my compositions in a workman-like manner, in different aspects and in large quantity, and thus enabled me to judge truly of the merits of them.

By the analogy of bone-ashes to cinders or ashes of other bodies, by the effects of them in my experiments, and by the observations which I have made on capital houses and garden walls which have been fronted or entirely stuccoed with my cement, some in the months of October November and December in the year 1778, others in the Spring,

Spring, the hottest weather, and the Autumn of 1779; I have been led into the following opinions concerning the agency of bone-ashes in calcareous cements.

THE mortar which contains bone-ashes, partakes in some degree of the compressibility and sponginess of their grains, and is the less liable to crack in setting, for the same reason that sponginess is, in any other body, an effectual preventative of fissures in drying; or because, any contraction of the lime paste, in consequence of the exhalation of its water, is confined to the circuit of the spongy grains compressed in beating trowelling and floating the cement, and is thereby prevented from running longitudinally to form fissures. The same texture of bone-ashes contributes to this effect, or causes it, upon other principles which are less exceptionable. There is no reason to doubt that bone-ashes, whose grains are tubulated in all possible directions, which greedily imbibe water and emit air, and which render the mortar in which they are mixed manifestly bibulous, facilitate the entry of acidulous gas into the cement; and that this matter entering as fast

as the water exhales, occupies the place of the water in the cement, and by preventing the contraction of it, prevents fissures. The speedy induration of the cement, which implies a quick or copious accession of acidulous gas, according to our experience, is a proof of this agency of bone-ashes, as well as an effect deducible from their texture: and from these premises we may easily conceive how they accelerate the setting of calcareous incrustations, and tend to secure them from the injuries of variable weather.

THESE properties of bone-ashes render them peculiarly useful in incrustations made within doors on principal walls; and the admixture of them in half the quantity of the lime, or in a greater quantity, is the improvement which I pointed out in the twentieth section, whereby the damp, which disfigures the common incrustations made in the circumstances there described, may be obviated, without our incurring the expence of lath-work.

THOSE who know that one-sixth part of charred bones, or about one-tenth part of
well

well burned bones, is phosphoric acid, may have some doubt concerning the duration of a cement in which they are mixed in large quantity, unless they consider that the strength of the cement does not depend on them, and that it is impossible for the phosphoric acid to quit the lime of bone-ashes, in order to dissolve the saturated lime of the cement. Tho' the bone-ashes should perish in a century, which is not probable, the cement is not likely to fail on this account, provided the quantity of them is not excessive.

Thus I surmounted the difficulties mentioned in the fourteenth section, and made my best calcareous cement applicable in all cementitious and crustaceous works external or internal, without inducing in it any disagreeable colour or other imperfection.

SECTION XXII.

The Specification made in Consequence of Letters Patent, illustrated with Notes.

IN order to guard against abuses, and to make some compensation for the expences and risques of the artists who publicly and boldly executed, on the great scale, what I had designed ; I secured an exclusive right in my cement, by virtue of his majesty's letters patent, on the eighth of January 1779 : I authorized Mr. James Wyatt the architect of Queen-Ann-street Cavendish-Square, to use it in the fullest extent, knowing that he, by his knowledge of this subject and his distinguished taste in architecture, will unite in it all the advantages of duration and elegance : I likewise extended this right to Samuel Wyatt the builder in Berwick-street Soho, who is well instructed, and provided with the means of executing any work with this cement, in the highest perfection : And I intend to reserve this privilege to them, until

til the public convenience requires that it should be extended to others, who are capable of making the same dispositions for the benefit of their employers, and for preserving the reputation of my invention free from the usual exactions of monopolists and the abuses of under-jobbers,

As the specification of these letters patent comprehends the most useful practical instructions deduced from the foregoing experiments and observations, and may serve as a concise recapitulation, I subjoin a transcript of it.

S P E C I F I C A T I O N.

To all to whom these presents shall come &c.

“ Now know ye that in compliance with
 “ the said proviso, I the said B. H. do here-
 “ by declare that my invention of a water
 “ cement or stucco, for building repairing and
 “ plastering walls, and for other purposes, is
 “ described in the manner following (that is
 “ to say) drift sand, or quarry¹ sand, which

¹ This is commonly called pit-sand.

“ consists

“ consists chiefly of hard quartose flat faced”
 “ grains with sharp angles; which is the
 “ freest, or may be most easily freed by
 “ washing, from clay, salts, and calcareous
 “ gypseous or other grains less hard and
 “ durable than quartz; which contains the
 “ smallest quantity of pyrites or heavy me-
 “ tallic matter inseparable by washing; and
 “ which suffers the smallest diminution of
 “ its bulk in washing in the following
 “ manner, is to be preferred before any
 “ other³. And where a coarse and a fine
 “ sand of this kind, and corresponding in
 “ the size of their grains with the coarse
 “ and fine sands hereafter described, cannot
 “ be easily procured, let such sand of the
 “ foregoing quality be chosen, as may be
 “ sorted and cleansed in the following
 “ manner.

“ LET the sand be sifted in streaming
 “ clear water, through a sieve which shall
 “ give passage to all such grains as do not

² THE twelfth section treats of this.

³ THE reasons of this preference are given in the fifteenth, sixteenth, nineteenth, and twentieth sections.

“ exceed

“ exceed one sixteenth of an inch in dia-
 “ meter; and let the stream of water and
 “ the sifting be regulated so that all the sand
 “ which is much finer than the Lynn-sand
 “ commonly used in the London glass-houses,
 “ together with clay and every other matter
 “ specifically lighter than sand, may be washed⁴
 “ away with the stream, whilst the purer and
 “ coarser sand, which passes thro’ the sieve,
 “ subsides in a convenient receptacle, and
 “ whilst the coarse rubbish and shingle⁵ re-
 “ main on the sieve, to be rejected.

“ LET the sand which thus subsides in
 “ the receptacle, be washed in clean stream-
 “ ing water, through a finer sieve, so as to
 “ be further cleansed and sorted into two
 “ parcels; a coarser, which will remain in
 “ the sieve which is to give passage to such
 “ grains of sand only as are less than one
 “ thirtieth of an inch in diameter, and
 “ which is to be saved apart under the name

⁴ THE grounds of this treatment appear in the twelfth and thirteenth section.

⁵ I find that I have used this word improperly, on bad authority. The reader is requested to read rubble instead of shingle throughout this specification.

“ of coarse sand; and a finer, which will
 “ pass through the sieve and subside in the
 “ water, and which is to be saved apart
 “ under the name of fine sand.—Let the
 “ coarse and the fine sand be dried sepa-
 “ rately, either in the sun, or on a clean iron
 “ plate set on a convenient furnace, in the
 “ manner of a sand heat ⁶.

“ LET lime be chosen ⁷ which is stone lime,
 “ which heats the most in flaking, and flakes
 “ the

⁶ THE sand ought to be stirred up continually until it is dried, and is then to be taken off; for otherwise the evaporation will be very slow, and the sand which lies next the iron plate, by being overheated, will be discoloured.

⁷ THE grounds of the instructions comprized in this paragraph, appear in the second, fourth, fifth and eleventh sections. The preference given to stone lime is founded on the present practice in the burning of lime, and on the closer texture of it, which prevents it from being so soon injured by exposure to the air, as the more spongy chalk lime is; not on the popular notion that stone lime has something in it whereby it excels the best chalk in the cementing properties. The real difference between these will be shewen in the next section.

THE gypsum contained in lime stone remains unaltered or very little altered in the lime, after the burning; but it is not to be expected that clay or martial matter should be found in their native state, in well burned lime; for they concrete or vitrifie with a part of the calcareous earth, and constitute the hard
 grains

“ the quickest when duly watered ; which
 “ is the freshest made and closest kept ;
 “ which dissolves in distilled vinegar with
 “ the least effervescence, and leaves the
 “ smallest residue insoluble, and in this re-
 “ spective the smallest quantity of clay gypsum
 “ or martial matter.

“ LET the lime chosen according to these
 “ important rules, be put in a brass-wired
 “ sieve to the quantity of fourteen pounds.
 “ Let the sieve be finer than either of the
 “ foregoing ; the finer, the better it will be :
 “ Let the lime be flaked^s by plunging it in
 “ a butt

grains or lumps, which remain undissolved in weak acids, or are separable from the flaked lime by sifting it immediately through a sieve.

^s THIS method of impregnating the water with lime is not the only one which may be adopted. It is however preferred before others, because the water clears the sooner in consequence of its being warmed by the flaking lime, and the gypseous part of the lime does not diffuse itself in the water so freely in this way, as it does when the lime is flaked to fine powder in the common method and is then blended with the water ; for the gypseous part of the lime flakes, at first, into grains, rather than into fine powder, and will remain on the sieve, after the pure lime has passed through, long enough to admit of the intended separation ; but when the lime is otherwise flaked, the gypseous grains have time to flake to a finer powder, and
 passing

“ a butt filled with soft water and raising it
 “ out quickly and suffering it to heat and
 “ fume, and by repeating this plunging and
 “ raising alternately and agitating the lime,
 “ until it be made to pass through the sieve
 “ into the water; and let the part of the
 “ lime which does not easily pass through the
 “ sieve be rejected: and let fresh portions of
 “ the lime be thus used, until as many⁹
 “ ounces of lime have passed through the
 “ sieve, as there are quarts of water in the butt.
 “ Let the water thus impregnated stand in the
 “ butt closely covered¹⁰ until it becomes clear;
 “ and through wooden¹¹ cocks placed at dif-
 “ ferent heights in the butt, let the clear liquor

passing through the sieve, dissolve in the water along with the
 lime. I have imagined that other advantages attended this
 method of preparing the lime water, but I cannot yet speak of
 them with precision.

⁹ If the water contains no more acidulous gas than is usually
 found in river or rain water, a fourth part of this quantity of
 lime, or less, will be sufficient.

¹⁰ THE calcareous crust which forms on the surface of the
 water ought not to be broke, for it assists in excluding the air
 and preventing the absorption of acidulous gas whereby the lime
 water is spoiled.

¹¹ Brass cocks are apt to colour a part of the liquor.

“ be

“ be drawn off as fast¹² and as low as the
 “ lime subsides, for use. This clear liquor I
 “ call the cementing liquor¹³. The freer the
 “ water is from saline matter, the better will
 “ be the cementing liquor made with it.

“ LET fifty-six pounds of the aforesaid
 “ chosen lime be flaked, by gradually sprinkl-
 “ ing on it, and especially on the unflaked
 “ pieces, the cementing liquor, in a close¹⁴
 “ clean place. Let the flaked part be im-
 “ mediately

¹² LIME water cannot be kept many days unimpaired, in any vessels that are not perfectly air-light. If the liquor be drawn off before it clears, it will contain whiting, which is injurious; and if it be not instantly used, after it is drawn limpid from the butt into open vessels, it will grow turbid again, and deposite the lime changed to whiting by the gas absorbed from the air. The calcareous matter which subsides in the butt, resembles whiting the more nearly, as the lime has been more sparingly employed; in the contrary circumstances, it approaches to the nature of lime; and in the intermediate state, it is fit for the common composition of the plaisterers for inside stucco.

¹³ AT the time of writing this specification I preferred this term before that of lime-water, on grounds which I had not sufficiently examined.

¹⁴ THE vapour which arises in the flaking of the lime contributes greatly to the flaking of these pieces which lie in its way; and an unnecessary waste of the liquor is prevented, by applying it to the lime heaped in a pit or in a vessel which may restrain

“ immediately ¹⁵ sifted through the last mentioned fine brass-wired sieve: Let the lime which passes be used instantly or kept in air-tight vessels, and let the part of the lime which does not pass through the sieve, be rejected ¹⁶.—This finer richer part of the lime which passes through the sieve, I call purified lime.

“ LET bone-ash be prepared ¹⁷ in the usual manner by grinding the whitest burnt bones, but let it be sifted to be much finer

restrain the issue of the vapour, and direct it through the mass. If more of the liquor be used than is necessary to flake the lime, it will create error in weighing the flaked powder, and will prevent a part of it from passing freely through the sieve. The liquid is therefore to be used sparingly, and the lime which has escaped its action is to be sprinkled apart with fresh liquor.

¹⁵ WHEN the aggregation of the lumps of lime is thus broken, it is impaired much sooner than it is in the former state, because the air more freely pervades it. This is shewn in the fifth section.

¹⁶ BECAUSE it consists of heterogeneous matter, or of ill burnt lime; which last will flake and pass through the sieve, if the lime be not immediately sifted after the flaking, agreeable to the text. The reason of this may be drawn from the fourth section.

¹⁷ THIS art is taught in the twenty-second section.

“ than

“ than the bone-ash commonly sold for
“ making cupels.

“ THE most eligible materials for making
“ my cement being thus prepared: Take
“ fifty-six pounds of the coarse sand and
“ forty-two pounds of the fine sand; mix
“ them on a large plank of hard wood
“ placed horizontally; then spread the sand
“ so that it may stand to the height of six
“ inches with a flat surface on the plank;
“ wet it with the cementing liquor; and let
“ any superfluous¹⁸ quantity of the liquor,
“ which the sand in the condition described
“ cannot retain, flow away off the plank.
“ To the wetted sand add fourteen pounds
“ of the purified lime in several successive
“ portions, mixing and beating them up toge-
“ ther in the mean time with the instruments
“ generally used in making fine mortar:
“ then add fourteen pounds of the bone-ash
“ in successive portions, mixing and beating
“ all together. The quicker and the more
“ perfectly these materials are mixed and
“ beaten together, and the sooner the ce-

¹⁸ The grounds of this practice are shewn in the twelfth section.

“ ment thus formed is used, the better ” it
 “ will be. This I call the water cement
 “ coarse grained, which is to be applied in
 “ building, pointing, plaistering, stuccoing,
 “ or other work, as mortar and stucco now
 “ are ; with this difference chiefly, that as
 “ this cement is shorter than mortar or com-
 “ mon stucco and dries sooner, it ought to
 “ be worked expeditiously in all cases, and
 “ in stuccoing it ought to be laid on by slid-
 “ ing the trowel upwards on it ; that the
 “ materials used along with this cement
 “ in building, or the ground on which it is
 “ to be laid in stuccoing, ought to be well
 “ wetted²⁰ with the cementing liquor, in

¹⁹ THESE proportions are intended for a cement made with-
 sharp sand, for incrustation in exposed situations, where it is
 necessary to guard against the effects of hot weather and rain.
 In general half this quantity of bone-ashes will be found suf-
 ficient ; and altho the incrustation in this latter case will not
 harden deeply so soon, it will be ultimately stronger provided
 the weather be favourable.

THE injuries which lime and mortar sustain, by exposure
 to the air, before the cement is finally placed in a quiescent
 state, appear in many parts of the foregoing pages ; and there-
 fore our cement is the worse for being long beaten, but the bet-
 ter as it is quickly beaten untill the mixture is effected, and no
 longer.

²⁰ SEE section vii. and page 75.

“ the

“ the instant of laying on the cement ; and
 “ that the cementing liquor is to be used when
 “ it is necessary to moisten the cement, or
 “ when a liquid is required to facilitate the
 “ floating of the cement.

“ WHEN such cement is required to be
 “ of a finer texture ; take ninety-eight pounds
 “ of the fine sand, wet it with the cementing
 “ liquor and mix it with the purified lime
 “ and the bone-ash in the quantities and in
 “ the manner above described, with this
 “ difference only, that fifteen pounds of
 “ lime, or²¹ thereabouts, are to be used instead
 “ of fourteen pounds, if the greater part of
 “ the sand be as fine as Lynn sand. This I
 “ call water cement fine grained. It is to
 “ be used in giving the last coating or the fi-
 “ nish to any work intended to imitate the
 “ finer grained stones or stucco. But it may
 “ be applied to all the uses of the water ce-
 “ ment coarse grained, and in the same
 “ manner.

²¹ SEE section xiii. The quantity of bone-ashes is not to be increased with that of the lime, for the reason given in page 176 ; but it is to be lessened as the exposure and purposes of the work will admit. See section xxii.

“ WHEN for any of the foregoing purposes of pointing, building, &c. such a cement is required much cheaper and coarser grained, then, much coarser clean sand than the foregoing coarse sand, or well washed fine ²² shingle is to be provided. Of this coarsest sand or shingle ²² take fifty-six pounds, of the foregoing coarse sand twenty-eight pounds and of the fine sand fourteen pounds; and after mixing these and wetting them with the cementing liquor in the foregoing manner, add 14 pounds, or somewhat less, of the ²³ purified lime, and then fourteen pounds or somewhat less of the bone-ash, mixing them together in the manner already described. When my cement is required to be white, white sand, white lime, and the whitest bone-ash are to be chosen. Grey sand and grey bone-ash formed of half burnt bones, are to be chosen to make the cement grey; and any other ²⁴ colour

²² Rubble.

²³ BECAUSE less lime is necessary as the sand is coarser. Section xii. and xiii.

²⁴ THE outlines of these arts are given in section xx.

“ of

“ of the cement is obtained, either by chuf-
 “ ing coloured fand, or by the admixture of
 “ the neceffary quantity of coloured talc in
 “ powder, or of coloured vitreous or metal-
 “ lic powders, or other durable²⁵ colouring
 “ ingredients commonly ufed in paint.

“ To the end that fuch a water cement
 “ as I have defcribed may be made as ufe-
 “ ful as is poffible in all circumftances ; and
 “ that no perfon may imagine that my
 “ claim and right under thefe Letters Pa-
 “ tent may be eluded by divers variations
 “ which may be made in the foregoing pro-
 “ ceffs without producing any notable de-
 “ fect in the cement ; and to the end that
 “ the principles of this art as well as the art
 “ itfelf of making my cement, may be ga-
 “ thered from this fpecification and perpe-
 “ tuated to the public, I fhall add the fol-
 “ lowing obfervations.

²⁵ THE known chemical properties of the feveral finer in-
 gredients ufed in paint or water colouring, and the experienced
 effects of the materials mentioned in the fifteenth, fixteenth,
 feventeenth, eighteenth, pineteenth and twentieth fections,
 are fufficient to direct the artift in the choice of thofe things
 which will induce colour, with the fmalleft injury to the
 incruftation.

“ THIS my water cement, whether the
 “ coarse or fine grained, is applicable in
 “ forming artificial stone, by making alter-
 “ nate layers of the cement and of flint, hard
 “ stone, or brick, in moulds of the figure
 “ of the intended stone, and by exposing the
 “ masses so formed, to the open²⁶ air to
 “ harden.

“ WHEN such cement is required for
 “ water²⁷ fences, two thirds of the prescribed

²⁶ But they must not be exposed to the rain, until they are almost as strong as fresh Portland stone; and even then they ought to be sheltered from it, as much as the circumstances will admit. See pages 68, 69, 114. These stones may be made very hard and beautiful, with a small expence of bone-ash, by soaking them, after they have dried thoroughly and hardened, in the lime-liquor, and repeating this process twice or thrice, at distant intervals of time. The like effect was experienced in incrustations, and is mentioned in page 114.

²⁷ To what I have said on this subject in page 124, I must add that, in my experiments, mortar made with terras powder, in the usual method, does not appear to form so strong a cement for water fences, as that made according to the specification, with coarse sand; and I see no more reason for avoiding the use of sand in terras mortar, than there would be for rejecting stone from the embankment. The bone-ashes meant in this place are the dark grey or black sort. I am not yet fully satisfied about the operation of them in this instance.

“ quantity

“ quantity of bone ashes are to be omitted;
 “ and in the place thereof an equal measure
 “ of powdered terras is to be used; and if
 “ the sand employed be not of the coarsest
 “ sort, more terras must be added, so that
 “ the terras shall be by weight one sixth part
 “ of the weight of the sand.

“ WHEN such a cement is required of the
 “ finest grain²⁸ or in a fluid form, so that
 “ it may be applied with a brush, flint powder,
 “ or the powder of any quartose or hard
 “ earthy substance may be used in the place
 “ of sand, but in a quantity smaller as the
 “ flint or other powder is finer; so that the

²⁸ THE qualities and uses of such fine calcareous cement are set forth in the thirteenth and twentieth sections. They are recommended chiefly for the purpose of smoothing and finishing the stronger crustaceous works, or for washing walls to a lively and uniform colour. For this last intention, the mixture must be as thin as new cream, and laid on briskly with a brush, in dry weather; and a thick and durable coat is to be made by repeated washing, but is not to be attempted by using a thicker liquor; for the coat made with this last is apt to scale, whilst the former endures the weather much longer than any other thin calcareous covering that has been applied in this way. Fine yellow ochre is the cheapest colouring ingredient for such a wash, when it is required to imitate Bath stone, or the warm-white stones.

“ flint powder or other such powder shall not
 “ be more than six times the weight of the
 “ lime, nor less than four times its weight.
 “ The greater the quantity of lime within
 “ these limits, the more will the cement be
 “ liable to crack by quick drying, and vice
 “ versa.

“ WHERE such sand as I prefer cannot be
 “ conveniently procured, or where sand cannot
 “ be conveniently washed and sorted,
 “ that sand which most resembles the mixture
 “ of coarse and fine sand above prescribed,
 “ may be used as I have directed,
 “ provided due attention is paid to the quantity
 “ of the lime, which is to be the greater²⁹ as the sand is the finer and vice
 “ versa,

“ WHERE sand cannot be easily procured,
 “ any durable stoney body, or baked
 “ earth grossly powdered³⁰ and sorted nearly
 “ to

²⁹ FURTHER instructions may be gathered from the thirteenth section. If sea sand be well washed in fresh water, it is as good as any other *round* sand,

³⁰ THE cement made with these and the proper quantities of purified lime and lime-water, are inferior to the best, as
 the

“ to the sizes above prescribed for sand, may
 “ be used in the place of sand, measure for
 “ measure, but not weight for weight, un-
 “ less such gross powder be as heavy spe-
 “ cifically as sand.

“ SAND may be cleansed from every softer
 “ lighter and less durable matter and from
 “ that part of the sand which is too fine, by
 “ various methods preferable²¹ in certain
 “ circumstances, to that which I have de-
 “ scribed.

“ WATER may be found naturally free from
 “ fixable gas selenite or clay: such water may,
 “ without any notable inconvenience, be used
 “ in the place of the cementing liquor; and
 “ water approaching this state will not re-
 “ quire so much lime as I have ordered, to

the grains of these powders are more perishable and brittle than those of sand. They will not therefore be employed, unless for the sake of evasion, or for want of sand: in this latter case the finer powder ought to be washed away,

²¹ THIS and the next paragraph is inserted with a view to evasions, as well as to suggest the easier and cheaper methods which may be adopted in certain circumstances, by artists who understand the principles which I have endeavoured to teach.

“ make

“ make the cementing liquor; and a cement-
 “ ing liquor sufficiently useful may be made
 “ by various methods of mixing lime and
 “ water in the described proportions, or
 “ nearly so.

“ WHEN stone lime cannot be procured,
 “ chalk lime or shell lime which best re-
 “ sembles stone lime, in the characters above
 “ written of lime, may be used in the manner
 “ described, except that³² fourteen pounds
 “ and a half of chalk lime will be required in
 “ the place of fourteen pounds of stone lime.
 “ The proportion of lime which I have pre-
 “ scribed above may be encreased without
 “ inconvenience, when the cement or stucco
 “ is to be applied where it is not liable to
 “ dry quickly; and in the contrary circum-
 “ stance this proportion may be diminished;
 “ and the defect of lime in quantity or
 “ quality may be very advantageously sup-

³² THIS relates to chalk lime burned with a sufficient quan-
 tity of fuel in kilns of the common construction. Chalk lime
 prepared as I shall shew in the next section, will go as far as
 stone lime, if not farther.

“ plied

“ plied ”, by causing a considerable quantity
 “ of the cementing liquor to soak into the
 “ work, in successive portions and at distant
 “ intervals of time, so that the calcareous
 “ matter of the cementing liquor, and the
 “ matter attracted from the open air, may
 “ fill and strengthen the work.

“ THE powder of almost every well
 “ dried or burnt animal substance may be
 “ used instead of bone-ash; and several
 “ earthy powders, especially the micaceous
 “ and the metallic; and the elixated ashes
 “ of divers vegetables whose earth will not
 “ burn to lime; and the ashes of mineral
 “ fuel, which are of the calcareous kind, but
 “ will not burn to lime; will answer the ends
 “ of bone-ash in some degree ”.

³³ THIS practice is noticed, as the remedy which may be
 used for the defects arising from evasive measures, and as the
 method of giving spongy incrustations containing bone-ashes,
 the greatest degree of hardness.

³⁴ The useful substitutes for bone-ashes, have been treated
 of in the foregoing sections: the metallic micaceous and earthy
 powders are not recommended in the text, but only enu-
 merated for reasons which influenced the style of this specification,
 and which lawyers will perceive.

“ THE

“ THE quantity of bone-ash described may
 “ be lessened without injuring the cement, in
 “ those circumstances especially which ad-
 “ mit the quantity of lime to be lessened, and
 “ in those wherein the cement is not liable
 “ to dry quickly. And the art of remedying
 “ the defects of lime may be advantageously
 “ practised to supply the deficiency of bone-
 “ ash, especially in building and in making
 “ artificial stone with this cement.

“ N. B. For inside work, the admixture
 “ of hair with this cement is useful.
 “ In witness whereof I the said B. H. &c.”

THE excellence of my cement depends
 first, on the figure size and purity of the
 sand; secondly on the purity of the lime,
 obtained in the choice of lime-stone, and in
 the perfect burning, and secured in the pre-
 servation of it from air, in my method of
 flaking, and in the separation of heterogeneous
 parts; thirdly on the use of strong and pure
 lime water in the place of common water;
 fourthly on the proportion of sands lime water
 and lime; fifthly, on the manner of mixing
 them; sixthly, on the knowledge of ingre-
 dients

dients and circumstances which are injurious or useful; seventhly, on the use of bone-ashes of determinate size; eighthly, on the art of suiting some of these to the several purposes; and finally on so many other particulars, as render it very difficult to give a more candid specification, in the usual compass, than this which I have enrolled, or to guard otherwise against evasions, than by anticipating them.

I do not think it necessary to insist more minutely on the mechanical arts of applying the coarser or finer calcareous cement, to produce the most agreeable effects, because they are known to so many workmen employed under Mess. Wyatt, and are so nearly related to those already known to the plaisterers, that they are not likely to be missed or lost.

SECTION XXIV.

Experimental Comparisons of Chalk-Lime with Stone-Lime. Advices to the Manufacturers of Chalk-Lime, concerning the Art of rendering it equal, if not superior, to Stone-Lime, for the Purposes of Builders Soap-Boilers and Sugar-Bakers.

ALL the authors whom I have consulted, who have treated of cementitious buildings and of lime, from the time of Vitruvius, who wrote on these subjects in the reign of the Roman Emperor Titus or before it, down to the present hour; and all the artists with whom I have conversed, agree in the opinion that lime prepared from the closest lime-stone makes a stronger cement than that which is made of spongy lime-stone, and that the lime of chalk particularly, is incapable of acting as effectually as the best stone lime, in cementitious works or incrustations which are exposed to the weather.

THIS

THIS universal and unquestioned notion had great influence with me in the course of my experiments, until I had discovered not only the fallacy of it, but the grounds which gave rise to it: both which I shall now expose, in the pleasing hope of rendering great services to many of my friends, and all who are proprietors of chalk-pits, or are obliged to use chalk-lime in their buildings.

THE experiments already mentioned afforded me a great many opportunities of comparing cements made with lime and sand, or with these and other ingredients in various proportions, and differing only in the kind of lime. In these comparisons I could not perceive that chalk lime, judiciously prepared and used, was in any respect inferior to the best stone lime: but I did not content myself with these. I made a great number of cements, with the sole view of collating the respective merits of these kinds of lime, in small and great incrustations, in masses made to resemble cut stone, in all exposures and seasons of the year; and after the strictest comparisons of those which contained lime in equal quantities and were treated
alike

alike in all respects, I was thoroughly convinced that my chalk lime was as good for any purpose of this kind, as the best stone lime in this kingdom; for I used the well-burned lime of Plymouth stone, which I reckon among the most excellent of our lime stones.

PLYMOUTH lime-stone loses seven sixteenths of its weight, in the conversion to lime, and becomes as white as chalk. Chalk looses a little more in the perfect burning. Plymouth lime leaves a small gypseous residue in the solution prescribed in the tenth page, which is preferable to that directed in the specification: chalk-lime leaves none. Therefore the chalk-lime chemically or technically tried, appears to be equal, if not superior to stone lime, in its cementing powers, when it is properly used.

THE prejudices entertained against chalk-lime may be traced to three sources. The first is that which is mentioned in the fourth section. The vulgar criterion of the due preparation of lime consists in the flaking: and as chalk, which has undergone a slight calcination

nation and thereby lost only a part of its acidulous gas, is capable of flaking, by reason of its sponginess; the manufacturers of chalk lime content themselves with the degree of calcination which renders it tractable or vendible, and thus bring it into disrepute.

THE second source is mentioned in the fifth section. Chalk lime imbibes acidulous gas, during its exposure to the air, much faster than stone lime, and is consequently more impaired or worse, at the time of using it in mortar, than stone lime kept in the same circumstances. As the lime may be greatly injured in this way, without flaking sensibly; and as there was no suspicion or measure of such injury, beyond what the flaking afforded; the acquired imperfection of chalk lime was considered as the very nature of it. In the thirtieth page it appears that a pound of chalk lime, placed in the quiescent air of a chamber, imbibes two ounces and a half of acidulous gas in two days, which is the shortest time in which lime is usually exposed, if we count from the moment of its being red hot to that of its being mixed in mortar, during which interval it is in the state of absorption.

THE third source I have discovered in the structure of lime kilns. The cavity of a lime-kiln has the figure of a truncated cone inverted. When the charge, consisting of lime stone and fuel alternately stratified, has burned for some time, the fuel is exhausted at the lower narrow extremity of the cavity, the lime in this part cools, and serves as a grate to the fuel and limestone above it, which continue to burn briskly, for eighteen hours or longer, after the lime beneath begins to cool. During this time the last-mentioned part of the lime is exposed to a strong current of air; and the whole charge of lime stands in the like current of air until the kiln is cooled, or the lime is withdrawn; which in common practice is seldom or never done before the sixtieth or seventieth hour after the combustion of the fuel commenced.

THE injury which lime stone sustains, in these circumstances, which I have often imitated in my laboratory, is not great; because this lime is much more compact than the chalk lime. But when we observe that the best pieces of chalk lime of the common kilns,
and

and those, which, after heating them sufficiently, I had left in the fire-place, exposed as they are in the usual process, are always effervescent; that good chalk lime, in a weaker current of air, imbibes more than three ounces of acidulous gas into each pound of it, in two days, according to the experiment of the thirtieth section; and that my chalk lime, which I remove from the fire-place as soon as it is sufficiently burned, is perfectly non effervescent; we find that the long experienced imperfections of fresh chalk lime are owing more, to the faulty construction of the kilns, and the ignorance of the manufacturer, than to any incapacity of chalk to yield excellent lime.

THE means of preparing chalk lime to equal or exceed stone lime, and of making the best stone lime, may be gathered from what I have said, and the following intimations. The kilns are to be made broader and shallower in the cavity which receives the charge: the circular wall inclosing this cavity, is to be continued tapering upwards, until it terminates in a lofty flue, in order to accelerate the combustion and increase the heat by a

quick-current of air to be regulated by opening or closing the door-way, which is to be left in the circular wall at a convenient height for the introduction of the charge. The massive walls of the lower cone are to be lined with fire brick or apyrous stone set in the best fire loam ; and are to be girded with iron. The fuel is to be so stratified with the lime stone or chalk, and the combustion is to be so conducted, that every part of the charge shall be sufficiently ventilated and heated, and that the lowest shall remain red hot until the whole is well burned. Then the current of air through the kiln is to be stopped, by closing the apertures at the bottom ; or the red hot lime is to be removed out of it, to cool in quiescent air, until it is fit to be inclosed in air-tight vessels. A cask of chalk lime is not to be opened until the moment when the workman is ready to flake the lime ; and the greatest expedition is to be used in the flaking, in making the mortar, and in applying it to use. By this treatment the chalk lime will answer every end of the best stone lime ; and stone lime may be prepared and preserved in the highest perfection which the nature of the lime stone can admit.

THE

THE manufacturer of chalk lime who first adopts these measures near London will profit by them : for good lime is not only better, but goes farther in building, than bad lime ; good chalk lime will answer the purposes of the soap-boiler, in half the quantity which they use of common chalk lime, the greater part of which serves only to waste their lees and clog their vatts ; and our sugar-bakers will not hesitate about the price of good chalk lime, when they find that it is totally soluble in pure water, and introduces no selenitic matter into the sugar. The exportation of lime to the West India Islands will be a further incitement towards the improvements which I have suggested, when the planters receive the information which I intend soon to give them, concerning the principles by which *lime, duly administered facilitates, but injudiciously used impedes the granulation* of the saccharine part of their cane juice.

SECTION XXV.

Directions to the Houses already stuccoed with the new Cement. Observations on the Objections of certain Artists ; on the cementitious Works of the Romans ; on the experienced and unequalled Duration of such Cements ; on the Cements of Lorient and others ; and on certain Uses of the Author's Cement.

THE inexperience of the workmen, their obstinate adherence to their own notions, and the opinion which they entertained that some of the rules prescribed to them were insisted on rather through an affectation of mystery than for any useful purpose, operated strongly against the best endeavours of Messieurs Wyatt, in the incrustations first made on the great scale for use or ornament. In consequence of these disadvantages, which will be obviated in future, their stucco, although it excels others beyond comparison and is far from being perishable, is not quite so hard as it might have been made. This I mention, lest these incrustations should

be

be mistaken for the best, which I have represented as exceeding Portland stone in hardness. These last demand a strict observance of the foregoing precepts respecting the season and the exposure as well as the materials and mechanical application of them.

The houses which have been stuccoed with this cement are the following :

The north front of Mr. Delme's house on the south side of Grosvenor-Square, stuccoed in November and December 1778.

The north and south fronts of Mr. Viner's house in Conduit-Street, Hanover-Square, and the moulded walls of the area behind it, stuccoed in the summer and autumn of 1779 : the fore-front representing Bath stone, the other front and the walls and mouldings of the area, closely imitating Portland stone.

Mr. Bond Hopkins's house at Wimbledon in Surry, stuccoed in the summer of 1779, in every aspect.

Mr. Birch's house at Hamstead near Birmingham, stuccoed in autumn 1779, in every aspect.

THESE were done under the direction of Mr. James Wyatt.

I MUST observe that the discoloured summit of the front of Mr. Viner's house, is natural stone; and that our cement never changes its colour, like those which contain white lead or oil. This house seems to be well finished. But when an incrustation is made in an improper season; when the parapet or gutters are defective, and the rain is suffered to penetrate through the spongy bricks and recent stucco; it is the fault of the workman and not of the cement, if the damp appears in the incrustation of the attic story, or if this part of it should never harden compleatly.

I HAVE not yet been informed of the work done by Mr. Samuel Wyatt, except the stuccoing of the Honourable Justice Willes's house at Little Grove East Barnet, on the northern southern and eastern sides, in September and October 1779; and a piece of incrustation representing a very coarse stone, made in November 1778, from the foundation to

to the height of the cellar story, on the eastern wall of Mr. Curzon's house in Davies-Street Grosvenor-Square. The earth had lain against this wall for many years : it was stuccoed immediately after the area had been opened to it, and whilst it was damp ; and by the mistake of the painter, the stucco was painted whilst it was fresh : I have not seen it since : but I am told that under all these disadvantages it is incomparably better than the piece of common stucco which meets it from above,

WHAT has been fairly shewn of the cement, in this public manner, has given greater satisfaction ; and Messrs. Wyatt are engaged to stucco a great number of capital houses with it next summer. These will be done in the highest perfection, because the workmen are now compliant and experienced,

AN impediment however still subsists to obstruct the progress of this art in the public estimation. Some interested persons diligently insinuate that this cement has not the sanction of long experience ; and that however promising it now appears, it may moulder like others in a few years hence : they likewise observe that only a superficial crust of
the

the above-mentioned stuccoes is sufficiently hard, but that the internal parts may easily be cut or broke: and they represent the cement as an expensive composition.

THIS publication, which shews it to be made of clean sorted sands, of bone-ashes, and of good lime in about half the quantity used in the common method of making mortar, renders an answer to the last-mentioned objection quite unnecessary.

The second objection may be thus considered. The same attractive power, which draws acidulous gas from the air into lime, must necessarily prevent any considerable quantity of the gas from entering deeply in a recent incrustation, until the lime at the surface is saturated with it, and consequently until a superficial layer of the cement is highly indurated. The same matter, which during its accession hardens this part, must likewise tend to render it closer in the texture and less freely pervious to that which is still necessary for the induration of the internal portions: and thus it happens that an incrustation grows harder at the surface, in one week,

week, than it does deeply in the substance, in a year, although bone-ashes be used to lessen the obstruction of the surface. Since therefore we know the reason why the interior parts of an incrustation cannot harden in a much longer time than is necessary for the hardening of the exterior; since the materials of the cement are the same in the central parts as well as at the superficies, and must be equally affected by acidulous gas when it can reach to them; since by our experience of old cements composed of lime and sand, we know that the induration extends equally through the mass of them, in the course of years; it is manifest that our stucco will harden in due time through the whole substance of it, as much as it does in a shorter time at the surface, and that the objection, founded on the internal weakness noticed in the first year, is futile.

To prove this by experiment, scrape away the hardened superficial stratum, as I have often done; and taking care to brush off all that you have loosened beneath, leave the new surface of the friable part of the cement exposed to the air for a few weeks. You will
find

find it to harden like the first surface, whilst the parts beneath it still continue brittle. You will perceive after a repetition of the like experiment in the same place, that every part of the stucco is capable of acquiring the hardness of the first surface, in a few days, and consequently that the whole will acquire it in the longer time necessary for the entrance of acidulous gas through the compact exterior crust.

WITH regard to the objections grounded on our short experience of this cement, I think they can have very little influence amongst informed men who know, from the writings of the antients, by the inspection of old cements, and by the analysis of them, that mortar made of lime and sand can endure every trial of the weather in the most exposed situations for a thousand years or more. Such objections deserve no better answer than ought to be given to an illiterate London bricklayer, who should object to the use of porphyry in building, because he has no certainty of its being so durable as the
bricks

bricks which he had for many years experienced.

I AM aware of the opinion, which is prevalent at this time, that the antients used something which is unknown to us in their mortar, and that this long lost ingredient is the cause of the duration and hardness of those cements which we so much admire in some of their structures. A notion founded on conjecture does not demand a serious discussion. I will therefore treat it as a subject of conversation rather than of argument.

VITRUVIUS in the fifth chapter of the second book of his architecture speaks thus of lime.

Quare autem cum recipit aquam, & arenam calx, tunc confirmat structuram, hæc esse causa videtur, quod e principiis uti cætera corpora, ita & saxa sunt temperata : & quæ plus habent aeris, sunt tenera : quæ aquæ, lenta sunt ab humore : quæ terræ, dura : quæ ignis, fragiliora. Itaque ex his saxa, si antequam coquantur, contusa minute, mixtaque arenæ conjiciantur in structuram, nec solidescunt, nec eam poterunt continere : cum vero
conjecta

conjecta in fornacem, ignis vehementi fervore correpta, amiserint pristinae soliditatis virtutem, tunc exustis, atque exhaustis eorum viribus, relinquuntur patentibus foraminibus, & inanibus: ergo liquor, qui est in ejus lapidis corpore, & aer cum exhaustus, & ereptus fuerit, habueritque in se residuum calorem latentem, intinctus in aqua prius, quam exeat ignis, vim recipit, & humore penetrante in foraminum raritates conservescit, & ita refrigeratus rejicit ex calcis corpore fervorem. Ideo autem quo pondere saxa conjiciuntur in fornacem, cum eximuntur, non possunt ad id respondere, sed cum expenduntur, eadem magnitudine permanente, excocto liquore circiter tertia parte ponderis imminuta esse inveniuntur. Igitur cum patent foramina eorum, & raritates, arenae mixtionem in se corripunt, & ita cohærescunt, siccescendoque cum cæmenis coeunt, & efficiunt structurarum soliditatem.

THE same ignorance of the nature of lime is betrayed by Alberti and later writers. And since we do not find any scientific rules prescribed by literary artists, for the composition of calcareous cements with such chosen and sorted materials as I have described, or in such proportions of them; and since it is highly improbable that the remembrance

membrance of an useful ingredient, or any knowledge once acquired in an art practised in so many countries and by so many different persons in every age, should have been lost; we have the most satisfactory reasons for concluding that the antients had no skill beyond that of our modern builders, in the preparation of lime or mortar.

THE ruins of Herculaneum, and other reliques of their works, furnish us with abundance of bad mortar and defective incrustations, which are instances of their ignorance of those principles by which the best cement might be made equally cheap. The total ruin and obliteration of many of their buildings, argue to the same end; for well cemented works suffer very little by dilapidation, by reason of the difficulty and expence of pulling them to pieces and applying the materials to other structures. If to these considerations I can add an exposition of the fortuitous circumstances which rendered some of their cements uncommonly hard and durable, I hope I shall not be suspected of ungenerous invidious motives, in saying that the aqueducts and other structures, which

which have been preserved to us through so many ages, by the strength of their cement, are monuments rather of the good luck, than of any extraordinary skill, of those who built them.

WHEN the neighbouring quarries afforded good lime stone, free from gypsum, and such as required to be well burned before it could flake freely; when the preparation of the lime, at the public expence, afforded no temptation for parsimony in fuel; and when the vicinity of the lime stone, and the quick consumption of the lime in great massive works, prevented those injuries which it sustains in long transportation and exposure, in the flaking of great quantities of it at once, or in the keeping of mortar made with it; the ignorance of the artists could not produce any defects dependent on bad lime, because necessity or chance enforced all that could have been sought by choice, in this instance.

WHEN the vicinity afforded sand, clean quartose sharp well sized and resembling our mixture of the coarse and fine; chance furnished

nished all that skill could aim at, in the choice and preparation of this article.

WHEN walls of immense thickness were constructed chiefly with small stones, in the way of boulder-work, the great consumption of mortar made every practicable saving of lime an object of great importance; and as the mortar must be made stiff for such work, it was neither convenient nor necessary to mix much lime in it, or to use fine sand in it, or to exclude the rubble from it: and thus, by motives of œconomy and convenience, rather than by any others, they were led to the measures which insured to the cement of such structures every perfection dependent on the goodness of lime and sand and on good, if not the best, proportions of them.

WHEN the stones used in building were recently dug, or collected from the beds of rivers, the artists needed no precautions against the bad effects of dry bibulous and dusty stones or bricks; and their works had, of necessity, every good quality attainable by the practice, which I commend, of soaking these materials. When their water was good,

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the

the cement abounding in lime was not much the worse for their ignorance of the use of lime water.

WHEN the structure was intended to stand by its own strength, rather than to depend on timbers ; and was by the solidity of its bearings and the diameter of its stoney substance, secured from agitation ; when the thickness of the walls, prevented the cement from being hastily dried, and afterwards secured it from being thoroughly wetted ; and when the enormous weight contributed to the approximation and cohesion of the parts of the cement to each other and to the stones ; every defect of cementitious buildings, of a contrary description, was obviated by the nature of the structure, which rendered it as perfect, in the hands of any artists, as the most consummate skill could make our modern slender tremulous bibulous walls.

IN the concurrence of these circumstances, we find excellent cements of great antiquity, which I need not point out to literary men : but since they are found no where else, that I have discovered ; and since it is not probable that the antients had any art of this kind unknown

known to the moderns, I think I am authorized to conclude that their best cementitious works, instead of being held forth as instances of their unequalled skill, ought rather to be considered as substantial proofs of the duration of mortar or stucco duly composed of sand and lime, beyond all others, and of the utility of these endeavours which I have made for preparing calcareous cements according to scientific principles, which enable us to make them in the highest perfection in all places, and to accommodate them to every purpose of use or ornament.

I HAVE studiously avoided strict comparisons of my cement or of the best Roman cements, with the oil cements; because the best of these is private property; not doubting that my liberal readers will give this silence a construction equally favourable to the proprietors and to me. But it is not necessary to lay myself under the same restraint respecting the reputed improvement of Monsieur Lorient, published in 1774 at Paris, in a pamphlet entitled, “ A treatise on a new discovery in the
“ art of building, made by Monsieur Lorient,
“ mechanic and pensionary to the king; in

“ which is announced, by order of his ma-
 “ jesty, the method of composing a cement
 “ or mortar fit for an infinity of works as
 “ well in building as in decoration.”

THE first half of this essay serves only to display the sanguine hopes and lively imagination of the author, which transported him beyond the bounds of his knowledge in this subject, and all the rules of physical induction. In the thirty-first page he says that
 “ the admixture of powdered quicklime, in
 “ any mortar made with flaked lime, is
 “ the most effectual method of giving it
 “ every desirable perfection; and that this
 “ is the chief discovery which he announces.” In the next page he gives the following prescription.

“ TAKE one part of brick-dust finely sift-
 “ ed, two parts of fine river sand screened,
 “ and as much old flaked lime as may be
 “ sufficient to form mortar with water, in
 “ the usual method, but so wet withal as to
 “ serve for the flaking of as much powdered
 “ quick-lime as amounts to one fourth of the
 “ whole quantity of brick-dust and sand.
 “ When

“ When the materials are well mixed, employ the composition quickly, as the smallest delay may render the application of it imperfect or impossible.”

IN the 40th page he says “ Another method of making the composition is, to make a mixture of the dry materials; that is to say, of the sand brick-dust and powdered quick-lime, in the prescribed proportion; which mixture may be put in sacks, each containing a quantity sufficient for one or two troughs of mortar. The abovementioned old flaked lime and water being prepared apart, the mixture is to be made, in the manner of plaister, in the instant when it is wanted, and even on the scaffold, and is to be well chafed with the trowel.”

To express Mr. Lorient's discovery briefly and dispassionately, I would say, when an ignorant artist makes mortar with whiting instead of lime, he can mend it considerably by adding lime to it: but his mortar will still be defective, in comparison with the best that may be made, by reason of the

old flaked lime or whiting. For on repeated trials I found this to be the true state of the case.

LIME sustains less injury in powdering small quantities of it in a covered vessel, than by flaking, in the usual method, with common water: and powdered lime, in the mixing of it with sand and water, excites a warmth in the mass, which greatly contributes to its drying or setting quickly. Mr. Lorient not knowing how to flake lime without impairing its cementing virtue, and taking the speedy exsiccation as an omen of perfect induration, imagined the prescription of powdered lime to be a great improvement.

If the powdering of lime, without exposing it much to the air, were not an expensive operation, I should have directed this powder to be used instead of water-flaked lime, for those parts of an *incrustation*, which are prevented from drying in due time, by their vicinity to the damp earth or to projections on which the rain lodges. The cement to be applied in such circumstances ought,

ought, as I said in the specification, page 202, to contain more lime than I have prescribed for other situations; and it will be found the better for being made with powdered quick-lime, because it will dry the sooner, and becoming pervious to air in consequence of the exhalation of its water, it will more speedily acquire that hardness which secures it from being exhausted of the lime by the constant moisture or the trickling rain.

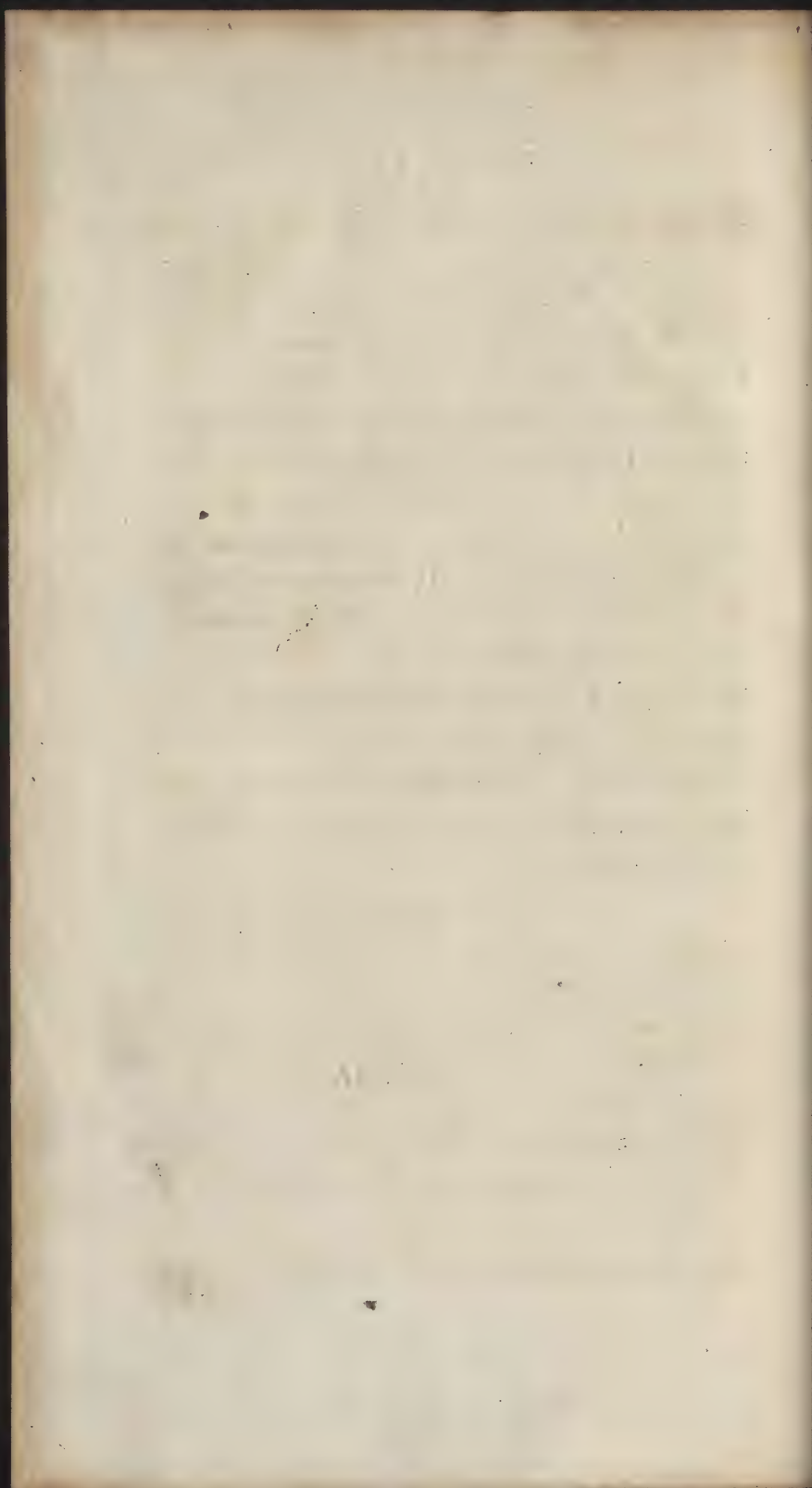
THE public are indebted to Mr. Hartley for the experimental proofs he has given of the efficacy of his method of securing houses from fire; and to lord Mahon for those judicious and expensive experiments by which he has shewn that a calcareous incrustation answers the purposes of Mr. Hartley's art. I am afraid that their good intentions will be frustrated by the indifference of men to distant or improbable evils, and their dislike to any immediate expence which affords no extemporary convenience or ornament. But altho' such motives of œconomy should dissuade us from adopting their measures in the fullest extent, we ought certainly to avail
ourselves

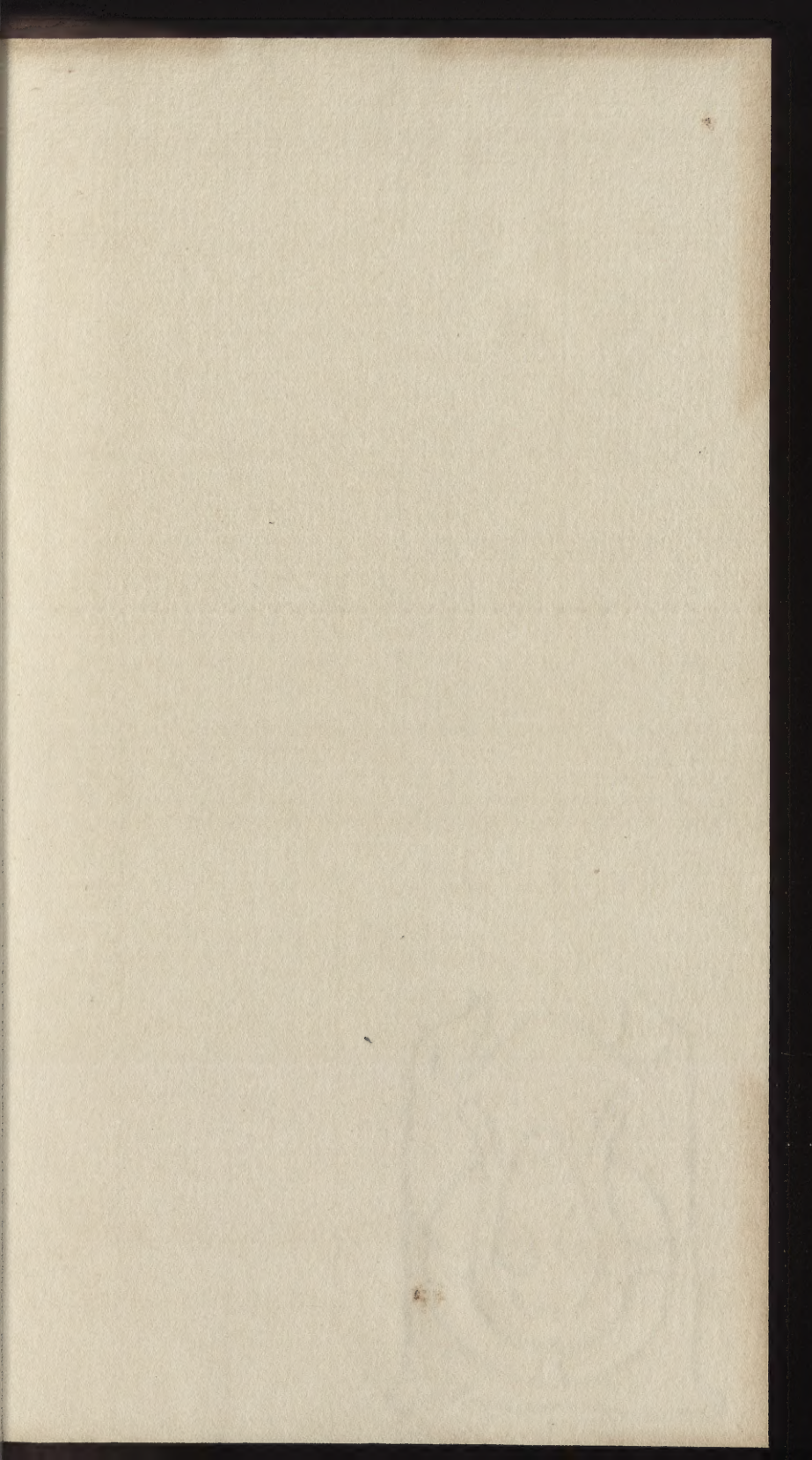
ourselves of the useful knowledge which they have imparted, so far as to prefer a safe and durable stucco, wherever it is applicable by the assistance of hair, before wainscot or wooden ornaments. For although no metallic or calcareous covering can secure the wood of a house from being charred by a great fire, the danger of others is lessened as the combustible materials are secured from the action of the air, and consequently from contributing to the deflagration.

I have thought that the small stones, which constitute the gravel chosen for our roads, could not be reduced to dust so soon as they now are, by the heavy carriages, if they were firmly bedded in a small quantity of coarse and good calcareous cement, so that the bodies which roll over them should rather compress them, than grind them against each other as they do at present. And as the frequent failures of pavement are manifestly owing to the infirmness of the ground and the looseness of the stones, I have imagined that a solid bed of cementitious work, in the manner of the Romans, and the setting of the paving stones in good mortar,

mortar, would ultimately lessen rather than enhance the expence. I offer these conjectures in the hope, that no body will presume to decide on the subject, who does not know the difference between the common mortar, and the best that can be made of lime and sand; and that some public-spirited man will make the experiment, where lime is cheap and the expence of pavement or of gravel is considerable. If the expence should be found too great for any public works of this kind, the same measures may nevertheless be tried in private areas and walks, in which the neatness, duration, and prevention of vegetation, may compensate for the extraordinary price.

T H E E N D.





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